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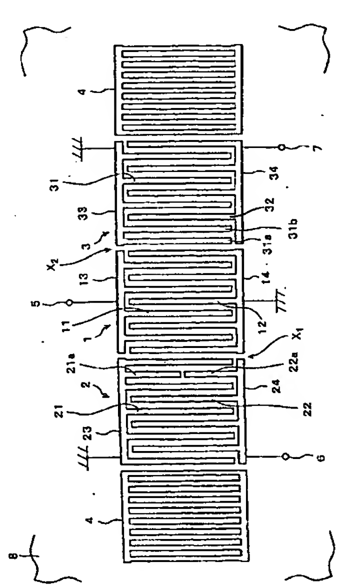
(54) Surface acoustic wave apparatus and communications unit

(57) Three longitudinal-coupling-resonator-type interdigital transducers (IDTs) (1-3) having a balanced-to-unbalanced conversion function are disposed on a piezoelectric substrate (8) in a direction in which a surface acoustic wave (SAW) propagates. Weighting is applied to at least one (2/3) of the IDTs. For example, among the electrode fingers of the IDT (2) located on the left side, an apodization-weighted electrode finger (22a) is provided for one of the electrode fingers positioned adjacent to the central IDT (1).

FIG. 1



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Description

BACKGROUND OF THE INVENTION

1. Field of the Invention

[0001] The present invention relates to a surface acoustic wave (SAW) apparatus for use in, for example, a filter having an unbalanced-to-balanced conversion function, and also to a communications unit using the SAW above-described apparatus.

2. Description of the Related Art

[0002] There has been significant technological progress in decreasing the size and weight of communications units, such as cellular telephones. As the frequency used in cellular telephones is increased, smaller SAW apparatuses are used for filters in such communications units. Additionally, multi-functional components are being developed for reducing the size and the number of the individual components of communications units.

[0003] In view of the above background, research is being actively conducted on SAW filters provided with a balanced-to-unbalanced conversion function, i.e., a so-called "balun function", used in the RF stage of cellular telephones. Such SAW filters are being used mostly in Global System for Mobile communications (GSM) cellular telephones. Patent applications concerning SAW filters provided with a balanced-to-unbalanced conversion function have been filed.

[0004] As a SAW filter having a balanced-to-unbalanced conversion function whose input impedance and output impedance are substantially the same, the configuration shown in Fig. 67 is known.

[0005] In the SAW filter apparatus shown in Fig. 67, a comb-like electrode (which is also referred to as an interdigital transducer and hereinafter referred to as an "IDT") 101 is disposed on a piezoelectric substrate 100. IDTs 102 and 103 are respectively formed on the left and right sides of the IDT 101 (in a SAW propagating direction). With this configuration, a three-IDT-type longitudinal-coupling-resonator-type SAW apparatus having a balanced-to-unbalanced conversion function is provided.

[0006] In the above-described SAW apparatus, reflectors 104 and 105 are disposed such that they sandwich the IDTs 102, 101, and 103 therebetween. Terminals 106 and 107 are provided as balanced signal terminals, and a terminal 108 is provided as an unbalanced signal terminal.

[0007] Another type of SAW apparatus, which is provided with a balanced-to-unbalanced conversion function whose input impedance and output impedance differ by, for example, four times, is disclosed in, for example, Japanese Unexamined Patent Application Publication No. 10-117123.

[0008] The SAW apparatus disclosed in the above publication includes, as shown in Fig. 68, a first SAW filter device 111 and a second SAW filter device 112 on a piezoelectric substrate. An output signal of the first SAW filter device 111 is 180° out of phase with an output signal of the second SAW filter device 112. The piezoelectric substrate is not shown in Fig. 68. With this configuration, the above-described SAW filter apparatus exhibits not only a filtering function, but also a balanced-to-unbalanced conversion function.

[0009] The first SAW filter device 111 is formed by cascade-connecting two three-IDT-type longitudinal-coupling-resonator-type SAW filters 118 and 124 which are symmetrical to each other with respect to the symmetrical line along the SAW propagating direction. That is, the first SAW filter device 111 is formed of two stages of filters.

[0010] In the longitudinal-coupling-resonator-type SAW filter 118, IDTs 114 and 115 are disposed such that they sandwich a central IDT 113 from the left and right sides (along the SAW propagating direction), and reflectors 116 and 117 are disposed such that they sandwich the IDTs 114, 113, and 115. Similarly, in the longitudinal-coupling-resonator-type SAW filter 124, IDTs 120 and 121 are disposed such that they sandwich a central IDT 119 from the left and right sides, and reflectors 122 and 123 are disposed such that they sandwich the IDTs 120, 119, and 121.

[0011] The second SAW filter device 112 is formed by cascade-connecting a longitudinal-coupling-resonator-type SAW filter 128, which is the same type as the longitudinal-coupling-resonator-type SAW filter 124, and a longitudinal-coupling-resonator-type SAW filter 127. The longitudinal-coupling-resonator-type SAW filter 127 is provided with a central IDT 133 whose phase is inverted (i.e., about 180°) by inverting the direction of the central IDT 113 of the longitudinal-coupling-resonator-type SAW filter 118.

[0012] One terminal 129 of the first SAW filter device 111 and one terminal 130 of the second SAW filter device 112 are electrically connected in parallel to each other, and the other terminals 131 and 132 are electrically connected in series to each other. The parallel-connected terminals 129 and 130 form an unbalanced terminal 108, while the series-connected terminals 131 and 132 form balanced terminals 106 and 107.

[0013] In the SAW apparatus having a balanced-to-unbalanced conversion function, the transmission characteristics within the pass band between the unbalanced terminal 108 and each of the balanced terminals 106 and 107 must have equal amplitude characteristics and 180°-out-of-phase characteristics. The extent to which such amplitude characteristics and phase characteristics are achieved is evaluated in terms of "the amplitude balance level" and "the phase balance level", respectively.

[0014] The amplitude balance level and the phase balance level are defined as follows. When the above-

described SAW apparatus having a balanced-to-unbalanced conversion function is considered as a three-port device, and when the unbalanced input terminal is port 1 and the balanced output terminals are port 2 and port 3, the amplitude balance level |A| and the phase balance level |B| are defined as follows:

$$A = |20\log(S21)| - |(20\log(S31)| \quad (1)$$

$$B = |\angle S21 - \angle S31| \quad (2)$$

where S21 indicates the transfer factor from port 1 to port 2, and S31 indicates the transfer factor from port 1 to port 3. Ideally, in the pass band of a SAW apparatus, the amplitude balance level is 0 dB, and the phase balance level is 180 degrees.

[0015] In the above-described SAW apparatus having balanced signal terminals, the balance levels between the balanced signal terminals are reduced. One of the reasons for this is as follows. The distance (indicated by 109 in Fig. 67) between the electrode finger connected to the balanced signal terminal 106 and the signal electrode finger of the IDT 102 is different from the distance (indicated by 110 in Fig. 67) between the electrode finger connected to the balanced signal terminal 107 and the signal electrode finger of the IDT 103 by 0.5 times the wavelength, which is determined by the pitch of the electrode fingers.

[0016] Then, the total capacitance of the electrode fingers connected to the balanced signal terminal 106 becomes different from that of the electrode fingers connected to the balanced signal terminal 107, and the conversion efficiency between an electrical signal and a SAW also becomes different between the balanced signal terminals 106 and 107. As a result, the balance levels are reduced.

[0017] Accordingly, the amplitude characteristics with respect to the frequency output from the balanced signal terminal 106 shown in Fig. 67 were measured by grounding the balanced signal terminal 107 as shown in Fig. 70. The amplitude characteristics with respect to the frequency output from the balanced signal terminal 107 shown in Fig. 67 were measured by grounding the balanced signal terminal 106 as shown in Fig. 71. The difference between the amplitude characteristics output from the balanced signal terminal 106 and those from the balanced signal terminal 107 is shown in Fig. 69. Fig. 69 shows that there is a large difference between the two amplitude characteristics, and this difference causes a reduction in the balance levels.

[0018] In the SAW apparatus having cascade-connected filter devices shown in Fig. 68, the polarities of the facing electrode fingers of two adjacent IDTs are not symmetrical between the first SAW filter device 111 and the second SAW filter device 112. This is another reason for reducing the balance levels.

[0019] More specifically, in the IDT 113, the portions located adjacent to the IDTs 114 and 115 (indicated by 125 in Fig. 68), i.e., the adjacent outermost electrode fingers between the IDTs 113 and 114, and the adjacent outermost electrode fingers between the IDTs 113 and 115 are ground electrode fingers. However, concerning the IDT 133, the adjacent outermost electrode fingers between the IDTs 133 and 134 (indicated by 126 in Fig. 68) and between the IDTs 133 and 135 (also indicated by 126 in Fig. 68) are a signal electrode finger and a ground electrode finger. If the polarities of the outermost electrode fingers between the adjacent IDTs are different between the left and right sides, the frequency and the amplitude level of the resonance mode shown in Figs. 72A and 72B are changed by the conversion between an electrical signal and a SAW.

[0020] If a SAW apparatus having a balanced-to-unbalanced conversion function is formed by two longitudinal-coupling-resonator-type SAW filter devices having different combinations of the outer electrode fingers of the adjacent IDTs, as in the SAW apparatus shown in Fig. 68, a change in the resonance mode reduces the balance levels between the balanced signal terminals.

[0021] A change in the resonance mode is also produced in a SAW filter apparatus formed by a single longitudinal-coupling-resonator-type SAW filter device, such as that shown in Fig. 73, thereby reducing the balance levels between the balanced signal terminals.

SUMMARY OF THE INVENTION

[0022] Accordingly, it is an object of the present invention to provide a SAW apparatus having a balanced-to-unbalanced conversion function which exhibits high balance levels between balanced signal terminals by offsetting a difference between the balanced signal terminals, and also to provide a communications unit using the above-described SAW apparatus.

[0023] In order to achieve the above object, according to one aspect of the present invention, there is provided a SAW apparatus including: at least one SAW filter having at least two IDTs formed on a piezoelectric substrate in a SAW propagating direction; and an input signal terminal and an output signal terminal for the SAW filter. At least one of the input signal terminal and the output signal terminal is connected to a balanced signal terminal, and weighting is applied to at least part of electrode fingers of the SAW filter.

[0024] With this configuration, by applying weighting to at least part of the electrode fingers of the SAW filter, balance characteristics (at least one of the amplitude balance, the phase balance, and the transmission characteristics) between balanced signal terminals can be adjusted. Thus, the balance characteristics can be improved.

[0025] In the aforementioned SAW apparatus, the above-described weighting may preferably be applied to at least part of the electrode fingers so as to improve

at least one of the amplitude balance level and the phase balance level between a pair of the balanced signal terminals.

[0026] The weighting may be applied to a few electrode fingers counted from the outermost electrode finger of at least one of the IDTs located adjacent to the other IDT.

[0027] The weighting may be applied to a few electrode fingers in the vicinity of the outermost electrode finger of at least one of the IDTs located adjacent to the other IDT.

[0028] The weighting may be applied to the electrode fingers located within one half a length in the SAW propagating direction from the outermost electrode finger of at least one of the IDTs located adjacent to the other IDT.

[0029] The weighting may be applied to the outermost electrode finger of at least one of the IDTs adjacent to the other IDT.

[0030] The electrode fingers located in a portion between the adjacent IDTs may be a ground electrode finger and a signal electrode finger, and the weighting may be applied to at least one of the ground electrode finger and the signal electrode finger.

[0031] The weighting may be applied to a signal electrode finger of the SAW filter.

[0032] The weighting may be applied to at least part of the electrode fingers of the IDT connected to the balanced signal terminal of the SAW filter.

[0033] The phase of at least one of the IDTs may be inverted with respect to the phase of the other IDT(s), and the weighting may be applied to at least part of the electrode fingers of the phase-inverted IDT.

[0034] The above-described weighting may be withdrawal weighting.

[0035] A dummy electrode may preferably be provided for a bus bar which faces a bus bar connected to the withdrawal-weighted electrode finger.

[0036] The weighting may be applied to at least two continuous ground electrode fingers including the outermost electrode finger of at least one of the IDT connected to the input signal terminal and the IDT connected to the output signal terminal, the ground electrode fingers being located such that it faces the other IDT.

[0037] A ground connecting portion may be disposed for connecting the electrode fingers of the adjacent IDTs which are connected to ground via the dummy electrode.

[0038] The above-described weighting may be apodization weighting in which the interdigital length of at least part of the electrode fingers is differentiated from the interdigital length of the other electrode fingers.

[0039] The above-described apodization weighting may preferably be applied substantially at the center of the interdigital length.

[0040] The apodization weighting may further be applied to the electrode finger adjacent to the apodization-weighted electrode finger, and a bending dummy electrode may be disposed such that it faces each of the two apodization-weighted electrode fingers.

[0041] The apodization-weighted electrode finger may be the outermost electrode finger of one of the adjacent IDTs, and a dummy electrode may be provided for the other IDT such that the dummy electrode faces the apodization-weighted electrode finger.

[0042] The dummy electrode may be grounded.

[0043] The above-described weighting may be duty ratio weighting in which the duty ratio of at least part of the electrode fingers is differentiated from the duty ratio of the other electrode fingers.

[0044] In the aforementioned SAW apparatus, the SAW filter may include at least three IDTs, and withdrawal-weighting may be applied to at least one of the adjacent IDTs, and the weighting applied to the IDT on one side of the SAW filter may be different from the weighting applied to the IDT on the other side of the SAW filter.

[0045] In the aforementioned SAW apparatus, two SAW filters may be provided, and withdrawal-weighting may be applied to each of the SAW filters, and the weighting applied to one of the SAW filters may be different from the weighting applied to the other SAW filter.

[0046] The SAW filter may include at least three adjacent IDTs, in which apodization-weighting may be applied to a few electrode fingers other than the outermost electrode finger of at least one of the adjacent IDTs on one side of the SAW filter, and withdrawal-weighting may be applied to the outermost electrode finger of at least one of the adjacent IDTs on the other side of the SAW filter. A dummy electrode connected to a bus bar which faces a bus bar connected to the withdrawal-weighted electrode finger is disposed in the withdrawal-weighted portion.

[0047] The SAW filter may include at least three adjacent IDTs, in which duty-ratio-weighting may be applied to the outermost electrode finger of at least one of the adjacent IDTs on one side of the SAW filter so that the duty ratio of the outermost electrode finger is differentiated from the duty ratio of the other electrode fingers, and withdrawal-weighting may be applied to the outermost electrode finger of at least one of the adjacent IDTs on the other side of the SAW filter. A dummy electrode connected to a bus bar which faces a bus bar connected to the withdrawal-weighted electrode finger is disposed in the withdrawal-weighted portion.

[0048] In the aforementioned SAW apparatus, two SAW filters may be provided, in which apodization-weighting may be applied to a few electrode fingers other than the outermost electrode finger of at least one of the adjacent IDTs of one of the SAW filters, and withdrawal-weighting may be applied to the outermost electrode finger of at least one of the adjacent IDTs of the other SAW filter. A dummy electrode connected to a bus bar which faces a bus bar connected to the withdrawal-weighted electrode finger is disposed in the withdrawal-weighted portion.

[0049] The SAW filter may be provided such that it possesses a balanced-signal-input and balanced-sig-

nal-output filtering function.

[0050] The SAW filter may be provided such that it possesses a balanced-signal-input and unbalanced-signal-output filtering function or an unbalanced-signal-input and balanced-signal-output filtering function.

[0051] At least one of the IDTs may be divided into two portions in the direction of the interdigital length of the IDT.

[0052] A pair of the balanced signal terminals may be connected to comb-like electrodes of one of the IDTs.

[0053] At least one of the IDTs may be divided into two portions in the direction in which the SAW propagates.

[0054] A grounded electrical neutral point does not have to be provided between a pair of the balanced signal terminals.

[0055] In the aforementioned SAW apparatus, two SAW filters may be provided such that they possess a balanced-signal-input and balanced-signal output filtering function.

[0056] The two SAW filters may be provided such that an output signal of one of the SAW filters is about 180° out of phase with an output signal of the other SAW filter, and the SAW filters may be provided such that they possess a balanced-signal-input and unbalanced-signal-output filtering function or an unbalanced-signal-input and balanced-signal-output filtering function.

[0057] A SAW filter may be cascade-connected to the unbalanced signal terminal.

[0058] The SAW filter may be a longitudinal-coupling-resonator-type SAW filter.

[0059] The above-described longitudinal-coupling-resonator-type SAW filter may include an odd number of IDTs.

[0060] The longitudinal-coupling-resonator-type SAW filter may include three IDTs.

[0061] The total number of electrode fingers of at least one of the IDTs of the longitudinal-coupling-resonator-type SAW filter may be an even number.

[0062] In the aforementioned SAW apparatus, at least three IDTs may be provided, and the total number of the electrode fingers of at least the IDT connected to the balanced signal terminal may be an even number.

[0063] In the aforementioned SAW apparatus, three IDTs may be provided, and the total number of the electrode fingers of at least the IDT located at the center of the IDTs may be an even number.

[0064] At least one SAW resonator may be connected in series to or in parallel with the SAW filter.

[0065] The SAW filter may be formed by cascade-connecting at least two SAW filter portions.

[0066] According to another aspect of the present invention, there is provided a SAW apparatus including: an input IDT having a plurality of electrode fingers; and an output IDT having a plurality of electrode fingers. The input IDT and the output IDT are disposed on a piezoelectric substrate in a SAW propagating direction so as to form a longitudinal-coupling-resonator-type. Weighting is applied to an inner electrode finger other than the outermost electrode finger of at least one of the input IDT and the output IDT.

[0067] One of the input IDT and the output IDT may be connected to a balanced side, and the input IDT or the output IDT connected to the balanced side may preferably include the weighted electrode finger. The SAW apparatus may be provided with an unbalanced-to-balanced conversion function.

[0068] With this configuration, by providing a weighted electrode finger for at least one of the input IDT and the output IDT, balance characteristics (amplitude balance, phase balance, and transmission characteristics) between output signals, in particular, between balanced output signals, can be adjusted. As a result, the balance characteristics can be improved.

[0069] In the aforementioned SAW apparatus, the weighted electrode finger may be located within one half a total width of all the electrode fingers of the corresponding IDT from the outermost electrode finger of the IDT.

[0070] At least two ground electrode fingers including the outermost electrode finger of at least one of the input IDT and the output IDT may preferably be sequentially provided, the outermost electrode finger being located such that it faces the other IDT.

[0071] With this arrangement, for example, it can be easily and reliably set that the balanced output signals be about 180° out of phase with each other.

[0072] The weighted electrode finger may preferably be set such that it controls the area of a no-electric-field portion formed between adjacent ground electrode fingers of at least one of the input IDT and the output IDT.

[0073] One of the input IDT and the output IDT may be connected to a balanced side, and the area of the no-electric-field portion of one of the two balanced IDTs may be substantially equal to the area of the non-electric-field portion of the other balanced IDT.

[0074] With this arrangement, the conversion balance from SAW energy to electric energy between the IDTs, in particular, between the output IDTs, can be adjusted, thereby improving balance characteristics.

[0075] A first grounded balance electrode finger may be formed to extend toward the weighted electrode finger so that the length of the first grounded balance electrode finger becomes equal to the length of the weighted electrode finger.

[0076] With this arrangement, the first grounded balance electrode finger can compensate for the no-electrode-finger portion formed by the shorter weighted electrode finger to some extent. It is thus possible to prevent a reduction in the balance characteristics caused by the no-electrode-finger portion.

[0077] A second grounded balance electrode finger may be formed to extend in a direction different from the direction of the weighted electrode finger so that the length of the second grounded balance electrode finger becomes equal to the length of the weighted electrode

finger, and a bending dummy electrode may be provided such that it faces the second grounded balance electrode finger and the weighted electrode finger.

[0078] With this arrangement, by providing a dummy electrode, the transmission characteristics can be improved while maintaining a high level of balance characteristics.

[0079] According to a further aspect of the present invention, there is provided a communications unit using one of the above-described SAW apparatuses. By using the SAW apparatus exhibiting excellent transmission characteristics, the communications unit can also exhibit a high level of transmission characteristics.

[0080] Further features and advantages of the present invention will become apparent from reading the following description of preferred embodiments thereof, given by way of example, with reference to the accompanying drawings, in which:

BRIEF DESCRIPTION OF THE DRAWINGS

[0081]

Fig. 1 is a schematic diagram illustrating a SAW apparatus according to a first embodiment of the present invention;
Fig. 2 illustrates the basic configuration of a SAW apparatus of a first comparative example;
Fig. 3 is a schematic diagram illustrating a SAW apparatus according to a modification made to the first embodiment of the present invention;
Fig. 4 is a schematic diagram illustrating a weighted area of the SAW apparatus of the first embodiment;
Fig. 5 is a graph illustrating the amplitude balance level (amplitude balance) of the SAW apparatus of the first embodiment;
Fig. 6 is a graph illustrating the phase balance level (phase balance) of the SAW apparatus of the first embodiment;
Fig. 7 is a graph illustrating the amplitude balance level (amplitude balance) of the SAW apparatus of the first comparative example;
Fig. 8 is a graph illustrating the phase balance level (phase balance) of the SAW apparatus of the first comparative example;
Fig. 9 is a schematic diagram illustrating another modification made to the first embodiment;
Fig. 10 is a schematic diagram illustrating still another modification made to the first embodiment;
Fig. 11 is a schematic diagram illustrating a further modification made to the first embodiment;
Fig. 12 is a schematic diagram illustrating a further modification made to the first embodiment;
Fig. 13 is a schematic diagram illustrating a further modification made to the first embodiment;
Fig. 14 is a schematic diagram illustrating a further modification made to the first embodiment;
Fig. 15 is a schematic diagram illustrating a further modification made to the first embodiment;
Fig. 16 is a schematic diagram illustrating a further modification made to the first embodiment;
Fig. 17 is a schematic diagram illustrating a further modification made to the first embodiment;
Fig. 18 is a schematic diagram illustrating a further modification made to the first embodiment;
Fig. 19 is a schematic diagram illustrating a further modification made to the first embodiment;
Fig. 20 is a schematic diagram illustrating a further modification made to the first embodiment;
Fig. 21 is a schematic diagram illustrating a further modification made to the first embodiment;
Fig. 22 is a schematic diagram illustrating a further modification made to the first embodiment;
Fig. 23 is a schematic diagram illustrating a further modification made to the first embodiment;
Fig. 24 is schematic diagram illustrating a SAW apparatus according to a second embodiment of the present invention;
Fig. 25 is a graph illustrating the amplitude balance level (amplitude balance) of the SAW apparatus of the second embodiment;
Fig. 26 is a graph illustrating the phase balance level (phase balance) of the SAW apparatus of the second embodiment;
Fig. 27 is a graph illustrating transmission characteristics of the SAW apparatus of the first embodiment;
Fig. 28 is a graph illustrating transmission characteristics of the SAW apparatus of the second embodiment;
Fig. 29 is a schematic diagram illustrating a SAW apparatus according to a third embodiment of the present invention;
Fig. 30 is a graph illustrating the amplitude balance level (amplitude balance) of the third embodiment and that of a second comparative example;
Fig. 31 is a graph illustrating the phase balance level (phase balance) of the third embodiment and that of the second comparative example;
Fig. 32 is a schematic diagram illustrating a SAW apparatus of the second comparative example;
Fig. 33 is a schematic diagram illustrating a SAW apparatus according to a fourth embodiment of the present invention;
Fig. 34 is a graph illustrating the amplitude balance level (amplitude balance) of the SAW apparatus of the fourth embodiment and that of the third comparative example;
Fig. 35 is a schematic diagram illustrating the reduced balance levels in the third comparative example;
Fig. 36 is a schematic diagram illustrating the improved balance levels in the fourth embodiment;
Fig. 37 is a schematic diagram illustrating a modification made to the fourth embodiment;
Fig. 38 is a schematic diagram illustrating the im-

proved balance levels in the modification shown in Fig. 37;
Fig. 39 is a schematic diagram illustrating another modification made to the fourth embodiment;
Fig. 40 is a schematic diagram illustrating the improved balance levels in the modification shown in Fig. 39;
Fig. 41 is a schematic diagram illustrating still another modification made to the fourth embodiment;
Fig. 42 is a schematic diagram illustrating a SAW apparatus according to a fifth embodiment of the present invention;
Fig. 43 is a graph illustrating the amplitude balance level (amplitude balance) of the fifth embodiment and that of a fourth comparative example;
Fig. 44 is a schematic diagram illustrating a SAW apparatus of the fourth comparative example;
Fig. 45 is a schematic diagram illustrating the reduced balance levels in the fourth comparative example;
Fig. 46 is a schematic diagram illustrating the improved balance levels in the fifth embodiment;
Fig. 47 is a schematic diagram illustrating a SAW apparatus according to a sixth embodiment of the present invention;
Fig. 48 is an enlarged diagram illustrating the SAW apparatus shown in Fig. 47;
Fig. 49 is a graph illustrating the amplitude balance level (amplitude balance) of the sixth embodiment and that of a fifth comparative example;
Fig. 50 is a schematic diagram illustrating a SAW apparatus of the fifth comparative example;
Fig. 51 is a graph illustrating a change in the amplitude balance level (amplitude balance) by varying the interdigital length in the SAW apparatus of the sixth embodiment;
Fig. 52 is a schematic diagram illustrating a SAW apparatus of a modification made to the sixth embodiment;
Fig. 53 is a schematic diagram illustrating a SAW apparatus of another modification made to the sixth embodiment;
Fig. 54 is a schematic diagram illustrating a SAW apparatus of still another modification made to the sixth embodiment;
Fig. 55 is a schematic diagram illustrating a SAW apparatus according to a seventh embodiment of the present invention;
Fig. 56 is a graph illustrating the amplitude balance level (amplitude balance) of the seventh embodiment and that of the second comparative example;
Fig. 57 is a graph illustrating the phase balance level (phase balance) of the seventh embodiment and that of the second comparative example;
Fig. 58 is a schematic diagram illustrating a modification made to the seventh embodiment;
Fig. 59 is a schematic diagram illustrating another modification made to the seventh embodiment;
Fig. 60 is a graph illustrating the amplitude balance level (amplitude balance) of the modification shown in Fig. 59 and that of the second comparative example;
Fig. 61 is a graph illustrating the phase balance level (phase balance) of the modification shown in Fig. 59 and that of the second comparative example;
Fig. 62 is a schematic diagram illustrating a SAW apparatus according to an eighth embodiment of the present invention;
Fig. 63 is a graph illustrating the amplitude balance level (amplitude balance) of the eighth embodiment and that of the second comparative example;
Fig. 64 is a graph illustrating the phase balance level (phase balance) of the eighth embodiment and that of the second comparative example;
Fig. 65 is a schematic diagram illustrating a SAW apparatus according to a ninth embodiment of the present invention;
Fig. 66 is a schematic block diagram illustrating a communications unit according to the present invention;
Fig. 67 is a schematic diagram illustrating the SAW apparatus of the first conventional example;
Fig. 68 is a schematic diagram illustrating the SAW apparatus of the second conventional example;
Fig. 69 is a graph illustrating a difference in insertion loss between balanced signal terminals of a known SAW apparatus;
Figs. 70 and 71 are schematic diagrams of configurations used for illustrating a difference in insertion loss between the balanced signal terminals of the known SAW apparatus;
Figs. 72A and 72B illustrate resonance modes in a SAW apparatus:

Fig. 72A is a graph illustrating the frequency of the resonance modes; and
Fig. 72B illustrates the current distribution of the resonance modes; and

[0082] Fig. 73 is a schematic diagram illustrating a SAW apparatus formed of a single longitudinal-coupling-resonator-type SAW filter device having a change in resonance mode.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

[0083] The present invention is described in detail below with reference to Figs. 1 to 66 through illustration of preferred embodiments.

First Embodiment

[0084] Fig. 1 illustrates a SAW apparatus constructed in accordance with a first embodiment of the present invention. The SAW apparatus shown in Fig. 1 has an un-

balanced-to-balanced conversion function and a filtering function, and includes an input IDT 1, output IDTs 2 and 3 disposed on the left and right sides of the input IDT 1 (along a SAW propagating direction), and reflectors 4 disposed outside the output IDTs 2 and 3 on a piezoelectric substrate 8. The input side and the output side are interchangeable.

[0085] More specifically, the output IDTs 2 and 3 are disposed such that they sandwich the input IDT 1 therebetween. The reflectors 4 are disposed such that they sandwich the IDTs 2, 1, and 3 therebetween, thereby reflecting a propagating SAW. The piezoelectric substrate 8 is formed of, for example, a 40±5° Y-cut X-propagating $LiTaO_3$ substrate.

[0086] The IDTs 1, 2, and 3 each have a strip-shaped base portion (bus bar) and two electrode portions provided with a plurality of strip-shaped electrode fingers. The electrode fingers extend orthogonally from one side of the base portion such that they are parallel to each other with uniform gaps. The electrode fingers also interdigitate with each other such that the sides thereof face each other.

[0087] In the above-configured IDTs 1, 2, and 3, the signal conversion characteristics and the pass band can be determined by setting the length and the width of each electrode finger, the pitch between adjacent electrode fingers, and the length by which the interdigitated electrode fingers face each other (hereinafter referred to as the "interdigital length"). In the first embodiment, the number of electrode fingers of the IDT 1 is set to 39, and the number of electrode fingers of each IDT 2 or 3 is set to 23.

[0088] The electrode fingers, the bus bars, and the reflectors 4 are formed of, for example, an aluminum (Al) electrode (foil), formed on the piezoelectric substrate 8 by, for example, a photolithographic technique.

[0089] In the first embodiment, in order to input an unbalanced signal and to output balanced signals, in the input IDT 1, signal electrode fingers 11 connected to an unbalanced input terminal 5 and ground electrode fingers 12 are interdigitated with each other as described above.

[0090] In the above-described IDT 1, the ground electrode fingers 12 are set so that the outermost electrode fingers, which are located at both ends in a SAW propagating direction, of the IDT 1 are ground electrode fingers 12. The outermost electrode fingers are positioned to face one of the outermost electrode fingers of the IDT 2 and one of the outermost electrode fingers of the IDT 3.

[0091] In the IDT 2, signal electrode fingers 22 connected to a balanced output terminal 6 and ground electrode fingers 21 are interdigitated with each other as described above. A bus bar 23 connected to the ground electrode fingers 21 is substantially aligned to a bus bar 13 connected to the signal electrode fingers 11 of the input IDT 1. The outermost electrode fingers of the IDT 2, which are positioned at both ends in a SAW propagating direction, are the ground electrodes 21.

[0092] In the IDT 3, signal electrode fingers 32 connected to a balanced output terminal 7 and ground electrode fingers 31 are interdigitated with each other as described above. A bus bar 33 connected to the ground electrode fingers 31 is substantially aligned to the bus bar 13 connected to the signal electrode fingers 11 of the input IDT 1.

[0093] A bus bar 14 connected to the ground electrode fingers 12 of the IDT 1 is substantially aligned to a bus bar 24 of the signal electrode fingers 22 of the IDT 2 and to a bus bar 34 of the signal electrode fingers 32 of the IDT 3.

[0094] In the first embodiment, the basic configuration of the output IDTs 2 and 3 is that they are structurally inverted with respect to each other. More specifically, in the IDT 2, the ground electrode fingers 21 and the signal electrodes 22 are alternately arranged, such as a ground electrode finger, a signal electrode finger, a ground electrode finger, and so on, starting from the electrode finger adjacent to the IDT 1. In contrast, in the IDT 3, before taking into account the withdrawal-weighting discussed below, the signal electrode fingers 32 and the ground electrode 31 fingers are alternately arranged, such as a signal electrode finger, a ground electrode finger, a signal electrode finger, and so on, starting from the electrode finger adjacent to the IDT 1.

[0095] With this arrangement, the amplitude difference between the IDTs 2 and 3 becomes approximately 0, and the phase difference therebetween becomes approximately 180°. Accordingly, the SAW apparatus is able to exhibit a balanced-to-unbalanced conversion function.

[0096] In the first embodiment, withdrawal weighting is applied to the outermost electrode finger of the IDT 3 adjacent to the IDT 1. A ground dummy electrode 31a is formed at the position in which the outermost electrode finger is withdrawal-weighted. In this specification withdrawal weighting means that an electrode finger is withdrawn, and another electrode finger is replaced. Accordingly, two ground electrodes, i.e., the dummy electrode 31a and a ground electrode finger 31b, are sequentially disposed in the IDT 3 adjacent to the IDT 1.

[0097] Additionally, in the first embodiment, an apodization-weighted electrode finger 22a is disposed at the position in which the signal electrode finger 22 next to the ground electrode finger 21 (outermost electrode finger) adjacent to the input IDT 1 is located. In this specification, apodization weighting means that the interdigital length of an electrode finger is changed. The length of the apodization-weighted electrode finger 22a is about one half the length of the other signal electrode fingers 22. That is, the interdigital length is adjusted.

[0098] A strip-shaped dummy electrode, which is an offset electrode finger, (first balance electrode finger) 21a extending from the grounded bus bar 23 is formed to fill in a space generated by the apodization-weighted electrode finger 22a. The dummy electrode 21a is ex-

tended toward the forward end of the apodization-weighted electrode finger 22a such that it is parallel to the adjacent ground electrode fingers 21 with uniform gaps.

[0099] The operation and the advantages of the first embodiment are as follows. For comparison, the schematic configuration of IDTs, which are not withdrawal-weighted or apodization-weighted, of a SAW apparatus having a balanced-to-unbalanced conversion function is shown in Fig. 2 as a first comparative example. In the configuration of the first comparative example, ground electrode fingers are disposed between the IDT 1 and an IDT 40, while a signal electrode finger and a ground electrode finger are disposed between the IDT 1 and an IDT 41. Accordingly, a no-electric-field portion 9 in which the conversion between an electrical signal and a SAW is not performed is disposed between the IDT 1 and the IDT 40. In contrast, the conversion between an electrical signal and a SAW is performed between the IDTs 1 and 41. Thus, the frequency and the amplitude level of a signal output from the balanced signal terminal 6 is different from those of a signal output from the balanced signal terminal 7. Additionally, the signals output from the balanced signal terminals 6 and 7 are not completely 180° out of phase with each other. As a result, the balance levels between the balanced signal terminals 6 and 7 are reduced.

[0100] In the first embodiment, the signal electrode finger of the IDT3 (in a comparable position to IDT 41) adjacent to the ground electrode of the IDT 1 is withdrawal-weighted, as shown in Fig. 3, and the dummy electrode 31a is formed at the position in which the signal electrode finger is withdrawal-weighted. That is, the two ground electrode fingers are disposed in the IDT 3 adjacent to the IDT 1. Accordingly, a difference of the conversion efficiency between an electrical signal and a SAW between the IDTs 1 and 3 and the IDTs 1 and 40 is offset. It is thus possible to provide a SAW apparatus having improved balance levels between the balanced signal terminals 6 and 7.

[0101] The provision of the dummy electrode 31a also prevents an increase in the loss caused by converting a SAW into a bulk wave. It is thus possible to provide a SAW apparatus exhibiting a low insertion loss within the pass band. The dummy electrode 31a does not have to be grounded, and may be a floating electrode. In this case, however, the balance levels between the balanced signal terminals 6 and 7 are reduced. Thus, the electrode 31a is preferably grounded.

[0102] In the configuration shown in Fig. 3, however, the no-electric-field portion 9 formed in the IDTs 1 and 3 is larger than that formed in the IDTs 1 and 40. Accordingly, the best balance levels between the balanced signal terminal 6 and 7 cannot be obtained. Thus, the apodization-weighted electrode finger 22a is set, as shown in Fig. 4, at the position in which the signal electrode finger 22 adjacent to the outermost electrode finger 21 is located, and the dummy electrode 21a is also provided. Accordingly, the size of the no-electric-field portion 9 in a boundary area X1 between the IDTs 1 and 2 becomes substantially equal to that in a boundary area X2 between the IDTs 1 and 3. It is thus possible to provide a SAW apparatus having further improved balance levels between the balanced signal terminals 6 and 7.

[0103] The provision of the dummy electrode 21a also prevents an increase in the loss caused by converting a SAW into a bulk wave. It is thus possible to provide a SAW apparatus having a low insertion loss within the pass band.

[0104] The grounded dummy electrodes 21a and 31a form the no-electric-field portions 9 with the adjacent ground electrode fingers 21 and 31b, respectively. Accordingly, the size of the no-electric-field portion 9 (an area in which the capacitance is formed) can be controlled by providing the dummy electrodes 21a and 31a, which is discussed in detail below.

[0105] Concerning the above-described apodization weighting, since a smaller weight is required for the signal electrode fingers, the no-electric-field portion 9 can be adjusted more efficiently by weighting the signal electrode fingers. However, apodization weighting may be applied to the ground electrodes.

[0106] Although in the first embodiment a weight is applied to the outermost electrode finger of the IDT 3, and a weight is applied to the electrode finger adjacent to the outermost electrode finger of the IDT 2, a weight may be applied to any electrode finger. However, in the resonance mode in the highest frequency range of the pass band (resonance mode indicated by C in Figs. 72A and 72B), which is most vulnerable to a difference in polarity between electrode fingers of adjacent IDTs, the current is most sharply changed at the electrode fingers between the adjacent IDTs, as shown in Fig. 72B. Thus, it is more effective, as shown in Fig. 4, if a weight is applied within a range of 1/2 of the SAW propagation length "a" in the IDT 2 from the outermost electrode finger adjacent to the IDT 1.

[0107] In the first embodiment, apodization weighting is performed by disposing the apodization-weighted electrode finger 22a, whose length is about one half the signal electrode finger 22. However, the amount apodization weighting may be adjusted as required. For example, the signal electrode finger 22 close to the IDT 1 may be apodization-weighted by about one fourth, and the subsequent signal electrode finger 22 may be apodization-weighted by about one fourth. In this case, advantages similar to those obtained by the first embodiment can be achieved.

[0108] The amplitude balance level and the phase balance level between the balanced signal terminals 6 and 7, with respect to the frequency, obtained by the first embodiment are shown in Figs. 5 and 6, respectively. For comparison, the amplitude balance level and the phase balance level between the balanced signal terminals 6 and 7, with respect to the frequency, in the first comparative example shown in Fig. 2 are shown in Figs.

7 and 8, respectively. The frequency range of the pass band for Extended Global System for Mobile Communications (EGSM) transmission filters is 880 MHz to 915 MHz.

[0109] The amplitude balance level between the balanced signal terminals 6 and 7 with respect to the above-mentioned frequency range ranges from -1.6 dB to +1.5 dB (having a deviation of 3.1 dB) for the first comparative example, while the corresponding amplitude balance level ranges from -0.7 dB to +1.2 dB (having a deviation of 1.9 dB) for the first embodiment. The level of the amplitude balance level is higher with a smaller deviation. Thus, in the first embodiment, the amplitude balance level is improved by about 1.2 dB. The phase balance level between the balanced signal terminals 6 and 7 for the first comparative example ranges from 172° to 189° (having a deviation of 17°), while the corresponding phase balance for the first embodiment ranges from 178° to 184° (having a deviation of 6°). The level of the phase balance level is higher with a smaller deviation. Thus, in the first embodiment, the phase balance level is improved by about 11°.

[0110] As described, in the first embodiment, weighting is applied to the SAW apparatus exhibiting the balanced-to-unbalanced conversion function configured by using a single longitudinal-coupling-resonator-type SAW filter device. It is thus possible to provide a SAW apparatus having improved balance levels between the balanced signal terminals 6 and 7 over known SAW apparatuses.

[0111] In the first embodiment, a single three-IDT-type longitudinal-coupling-resonator-type SAW filter device is used. However, the present invention is not restricted to this configuration, and the SAW apparatus may be configured in any manner as long as it is provided with the balanced signal terminals 6 and 7. In this case, advantages similar to those obtained by the first embodiment can be achieved.

[0112] For example, Fig. 9 illustrates a SAW apparatus having a balanced-to-unbalanced conversion function using a longitudinal-coupling-resonator-type SAW filter having five-IDTs (balanced signal terminals 401 and 402, and an unbalanced signal terminal 403). As in this type of SAW apparatus, in a SAW apparatus using a longitudinal-coupling-resonator-type SAW filter having more than three-IDTs or having two IDTs, the advantages of the present invention can be offered. The type of filter used in the present invention is not limited to a longitudinal-coupling-resonator-type SAW filter, and a transversal SAW filter or a length-coupling-resonator-mode SAW filter may be employed, in which case, advantages similar to those obtained by the first embodiment can be achieved.

[0113] In the first embodiment, the SAW apparatus is provided with a balanced-to-unbalanced conversion function. However, as in SAW apparatuses shown in Figs. 10 and 11, a balanced signal may be input and a balanced signal may be output. More specifically, in Fig. 10, balanced signal terminals 501 and 502 form a pair, and balanced signal terminals 503 and 504 form a pair. In Fig. 11, balanced signal terminals 601 and 602 form a pair, and balanced signal terminals 603 and 604 form a pair. In this case, advantages similar to those obtained by the first embodiment can be achieved.

[0114] In the first embodiment, the SAW apparatus having a balanced-to-unbalanced conversion function is configured by using a single longitudinal-coupling-resonator-type filter. However, the present invention is not restricted to this type of configuration.

[0115] For example, as shown in Fig. 12, balanced signal terminals 701 and 702 may be connected to comb-like electrodes of a single IDT in a single longitudinal-coupling-resonator-type SAW filter. Thus, the configuration shown in Fig. 12 does not have an electrical neutral point. In Fig. 12, reference numeral 703 indicates an unbalanced signal terminal. As shown in Fig. 13, one IDT is divided in the direction of the interdigital length so as to change the impedance. In Fig. 13, reference numerals 801 and 802 indicate balanced signal terminals, and 803 indicates an unbalanced signal terminal. In Fig. 14, one IDT is divided in a SAW propagating direction, and balanced signal terminals 901 and 902 are connected to the divided comb-like electrodes. In Fig. 14, reference numeral 903 designates an unbalanced signal terminal. For all these modifications, advantages similar to those obtained by the first embodiment can be achieved.

[0116] As shown in Fig. 15, an unbalanced signal terminal 1003 may be connected to inverted comb-like electrodes of IDTs on the left and right sides. It is thus possible to provide a SAW apparatus having an improved attenuation outside the pass band. In Fig. 15, reference numerals 1001 and 1002 designate balanced signal terminals.

[0117] Additionally, a plurality of longitudinal-coupling-resonator-type SAW filters may be combined to form a SAW apparatus having a balanced-to-unbalanced conversion function. In this case, advantages similar to those obtained by the first embodiment can be achieved.

[0118] For example, as shown in Fig. 16, two longitudinal-coupling-resonator-type SAW filters 1104 and 1105 may be provided such that output signals from the SAW filters 1104 and 1105 are about 180° out of phase with each other. IDTs connected to balanced signal terminals 1101 and 1102 may be connected in series to each other, and IDTs connected to an unbalanced signal terminal 1103 may be connected in parallel to each other. As shown in Fig. 17, a single longitudinal-coupling-resonator-type SAW filter 1201 may be cascade-connected to the configuration shown in Fig. 16. As shown in Fig. 18, weights may be applied to the configuration shown in Fig. 68. With these modifications, advantages similar to those obtained by the first embodiment can be achieved.

[0119] In the configuration in which longitudinal-cou-

pling-resonator-type SAW filters are cascade-connected, not only the balance levels between balanced signal terminals can be improved, but also, the attenuation outside the pass band can be increased. In this case, as shown in Fig. 19, IDTs 1303 and 1304 may be inverted relative to each other so that electrical signals transmitting in signal lines 1301 and 1302 used for cascade-connecting two longitudinal-coupling-resonator-type SAW filters are about 180°out of phase with each other. Similarly, IDTs 1307 and 1308 may be inverted relative to each other so that electrical signals transmitting in signal lines 1305 and 1306 are about 180° out of phase with each other. With this arrangement, a SAW apparatus having further improved balance levels between balanced signal terminals can be obtained.

[0120] Additionally, as shown in Fig. 20, a single longitudinal-coupling-resonator-type SAW filter 1401 may be cascade-connected to the SAW apparatus shown in Fig. 12, in which case, advantages similar to those obtained by the first embodiment can be achieved. With this configuration, a SAW apparatus having not only improved balance levels between balanced signal terminals, but also an increased attenuation outside the pass band can be obtained. In this case, as shown in Fig. 21, IDTs 1503 and 1504 are inverted relative to each other so that electrical signals transmitting in signal lines 1501 and 1502 are about 180° out of phase with each other, as in the configuration shown in Fig. 19. It is thus possible to provide a SAW apparatus exhibiting further improved balance levels between balanced signal terminals.

[0121] When cascade-connecting two or more longitudinal-coupling-resonator-type SAW filters, the same type of longitudinal-coupling-resonator-type SAW filter does not have to be used. For example, for adjusting the input impedance and the output impedance, the interdigital length may be differentiated between SAW filters. For increasing the attenuation outside the pass band, the number of pairs of electrode fingers of an IDT, the center-to-center distance between adjacent IDTs, or the center-to-center distance between an IDT and a reflector may be differentiated between SAW filters. Accordingly, different designs of SAW filters may be used.

[0122] Although in the first embodiment the total number of electrode fingers of each IDT is set to an odd number, it may be an even number. In particular, as shown in Fig. 22, the total number of electrode fingers of the central IDT connected to balanced signal terminals may be an even number. With this modification, advantages similar to those obtained by the first embodiment can also be achieved.

[0123] In this case, the horizontal symmetrical characteristics with respect to the center of the longitudinal-coupling-resonator-type SAW filter can be enhanced, and the number of electrode fingers connected to one balanced signal terminal is equal to that connected to the other balanced signal terminal. It is thus possible to provide a SAW apparatus having further improved balance levels between balanced signal terminals.

[0124] As shown in Fig. 23, SAW resonators 1601 and 1602 may be connected in series to each other. Alternatively, SAW resonators may be connected in parallel to each other, though they are not shown. Alternatively, series-connected SAW resonators and parallel-connected SAW resonators may be connected to each other. In this case, a SAW apparatus having not only improved balance levels between balanced signal terminals, but also an increased attenuation in a range in the vicinity of the pass band, can be obtained.

Second Embodiment

[0125] A second embodiment is described below with reference to Figs. 24 through 28. In the second embodiment, components having functions similar to those of the SAW apparatus shown in Fig. 1 are indicated by like reference numerals, and an explanation thereof is thus omitted.

[0126] In a SAW apparatus constructed in accordance with the second embodiment of the present invention, instead of performing withdrawal weighting or apodization weighting employed in the first embodiment, series weighting is applied, as shown in Fig. 24. That is, an IDT 25 is substituted for the IDT 2 used in the first embodiment.

[0127] In the IDT 25, instead of the dummy electrode finger 21a of the IDT 2, an apodization-weighted electrode finger 21b, which is positioned subsequent to the apodization-weighted electrode finger 22a and is made shorter as in the apodization-weighted electrode finger 22a, is provided. A dummy electrode finger (second balance electrode finger) 25a is provided such that it is separated from the apodization-weighted electrode fingers 22a and 21 b (i.e., the dummy electrode finger 25a is floating).

[0128] The dummy electrode finger 25a is extended by the same length as the apodization-weighted electrode finger 22a between and substantially in parallel to the apodization-weighted electrode finger 22a and the subsequent signal electrode finger 22, passes between the forward end of the apodization-weighted electrode finger 22a and the forward end of the apodization-weighted electrode finger 21b, and is extended between and substantially in parallel to the apodization-weighted electrode finger 21b and the outermost ground electrode finger 21.

[0129] In a SAW apparatus having the IDT 25, the amplitude balance level and the phase balance level in a range in the vicinity of the pass band were measured. The results are shown in Figs. 25 and 26, respectively. Fig. 25 shows that the amplitude balance level between the balanced signal terminals in a frequency range of the pass band used for EGSM transmission filters ranges from -0.7 dB to +1.2 dB (having a deviation of 1.9 dB), which is the same result as the first embodiment. Fig. 26 reveals that the phase balance level between

the balanced signal terminals ranges from 177° to 182° (having a deviation of 5°). Accordingly, the balance level is improved over the first embodiment by 1°.

[0130] The transmission characteristics within the pass band with respect to the frequency obtained by the first embodiment are shown in Fig. 27, and the transmission characteristics within the pass band with respect to the frequency obtained by the second embodiment are shown in Fig. 28. For comparing the two transmission characteristics, ripple A is generated (see Fig. 27) within the pass band in the first embodiment, while ripple A is not generated (see Fig. 28) within the pass band in the second embodiment. Thus, in the second embodiment, the deviation is smaller within the pass band.

[0131] As described above, by performing series weighting, which is a modification of apodization weighting, it is possible to provide a SAW apparatus having improved balance levels between the balanced signal terminals and a smaller deviation within the pass band.

[0132] Additionally, in the second embodiment, the generation of ripples is inhibited in the transmission characteristics, and thus, the SAW apparatus of the second embodiment exhibits more excellent transmission characteristics.

Third Embodiment

[0133] A third embodiment is discussed in detail below with reference to Figs. 29 through 32. Fig. 29 illustrates a SAW apparatus constructed in accordance with the third embodiment of the present invention. In the third embodiment, the present invention is discussed in the context of a PCS receiving filter.

[0134] In the SAW apparatus of the third embodiment, on a piezoelectric substrate 200, a three-IDT-type longitudinal-coupling-resonator-type SAW filter 201, and SAW resonators 202 and 203, which are connected in series to the SAW filter 201, are formed of an Al electrode (foil) by, for example, a photolithographic technique. The piezoelectric substrate 200 may be formed of a 40±5° Y-cut X-propagating $LiTaO_3$ substrate. The SAW filter 201 is substantially the same as that shown in Fig. 10.

[0135] In the SAW filter 201, IDTs 204 and 206 are disposed such that they sandwich a central IDT 205, which is connected to balanced signal terminals 210 and 211, from the left and right sides (along a SAW propagating direction). Reflectors 207 and 208, which reflect SAWs from the IDTs 204, 205, and 206, are disposed outside the IDTs 204 and 206, respectively (along a SAW propagating direction). That is, the IDTs 204, 205, and 206 and the reflectors 207 and 208 are disposed on the SAW propagation path so that the lengths of the electrode fingers are perpendicular to the SAW propagating direction.

[0136] In the SAW filter 201, the pitch between some electrode fingers in a portion (indicated by 213 in Fig. 29) between the adjacent IDTs 204 and 205, and the pitch between some electrode fingers in a portion (indicated by 214 in Fig. 29) between the adjacent IDTs 204 and 206 are made narrower than the pitch between the other electrode fingers.

[0137] In the above-described SAW apparatus, reference numeral 209 designates an unbalanced signal terminal. Accordingly, the IDTs 204 and 206 are connected to the unbalanced signal terminal 209. The IDT 204 includes signal electrode fingers 204a and ground electrode fingers 204b, and the IDT 206 includes signal electrode fingers 206a and ground electrode fingers 206b. The IDT 205 is connected to the balanced signal terminals 210 and 211, and includes signal electrode fingers 205a and 205b. Thus, in the third embodiment, weighting is applied to the configuration of a SAW apparatus without an electrical neutral point.

[0138] The SAW resonators 202 and 203 are connected between and in series to the unbalanced signal terminal 209 and the IDTs 204 and 206 via a signal line 212. The SAW resonator 202 includes an IDT 202a, and reflectors 202b and 202c disposed such that they sandwich the IDT 202a along a SAW propagating direction. The SAW resonator 203 includes an IDT 203a, and reflectors 203b and 203c disposed such that they sandwich the IDT 203a along a SAW propagating direction.

[0139] The features of the third embodiment are as follows. Withdrawal weighting is applied to an electrode finger 219 of the IDT 206 adjacent to the IDT 205. Additionally, the signal electrode finger 206a of the IDT 206 most adjacent to the IDT 205 is withdrawal-weighted.

[0140] In the third embodiment, in order to maintain a spacing between the IDTs 205 and 206, the interdigital length, the pitch, the duty ratio, and the width of the electrode finger 219 are set to be the same as those of the narrower-pitch ground electrode fingers 206b. With this arrangement, in the IDT 206, a plurality of (for example, two) ground electrode fingers 206b are sequentially disposed at the portion adjacent to the IDT 205.

[0141] When the wavelength determined by the narrower pitch of the electrode fingers is indicated by λI_2 (indicated by 213 and 214 in Fig. 29), and when the wavelength determined by the pitch of the other electrode fingers is indicated by λI_1, detailed design parameters of the SAW filter 201 are as follows (the number in parentheses indicates the number of narrower-pitch electrode fingers):

- interdigital length W: 60.6 λI_1;
- number of pairs of electrode fingers of IDT 204: 29 (4);
- number of pairs of electrode fingers of IDT 205: (4) 44(4);
- number of pairs of electrode fingers of IDT 206: (4) 29;
- IDT wavelength λI_1: 2.06 μm;
- IDT wavelength λI_2: 1.88 μm;
- reflector wavelength λR: 2.07 μm;

number of electrode fingers of reflector: 100;
IDT pitch: 0.50 λI_2;
pitch between wider pitch electrode finger (λI_1) and narrower-pitch electrode finger (λI_2) (indicated by 215, 216, 217, and 218): 0.25 λI_1 + 0.25 λI_2;
pitch between IDT and reflector: 0.47 λR;
duty ratio (for IDT and reflectors): 0.60; and
electrode thickness: 0.080 λI_1.

[0142] Detailed design configuration of the SAW resonator 202 is shown as follows:

interdigital length W: 40.6 λ;
number of pairs of electrode fingers of IDT: 241;
wavelength λ (for IDT and reflectors): 1.97 μm;
number of electrode fingers of reflectors: 30
center-to-center distance between IDT and reflector: 0.50 λ;
duty ratio (for IDT and reflectors): 0.60; and
electrode thickness: 0.084 λ.

[0143] Detailed design parameters of the SAW resonator 203 are as follows:

interdigital length W: 49.1 λ;
number of pairs of electrode fingers of IDT: 401;
wavelength λ (for IDT and reflectors): 2.04 μm;
number of electrode fingers reflectors: 30;
center-to-center distance between IDT and reflector: 0.50 λ;
duty ratio (for IDT and reflectors): 0.60; and
electrode thickness: 0.080 λ.

[0144] The characteristics of the third embodiment were measured, and the results are shown in Figs. 30 and 31. More specifically, the amplitude balance level between the balanced signal terminals with respect to the frequency obtained by the third embodiment is shown in Fig. 30, and the phase balance level obtained by the third embodiment are shown in Fig. 31.

[0145] For comparison, the amplitude balance level and the phase balance level of a SAW filter having an IDT 206c, as shown in Fig. 32, instead of the IDT 206 are shown Figs. 30 and 31 as a second comparative example. In the IDT 206c, withdrawal weighting is not performed at the portion between two adjacent IDTs.

[0146] The configuration of the SAW apparatus of the second comparative example is the same as that of the third embodiment, except that the IDT 206c, which is not withdrawal-weighted, is used instead of the IDT 206. The frequency range of the pass band used for PCS receiving filters is 1930 MHz to 1990 MHz.

[0147] In this range, the maximum amplitude balance level of the second comparative example ranges from -1.6 dB to +0.7 dB (having a deviation of 2.3 dB). In contrast, the maximum amplitude balance level of the third embodiment ranges from -1.5 dB to +0.7 dB (having a deviation of 2.2 dB). Accordingly, the amplitude balance level is improved by about 0.1 dB. The phase balance level of the second comparative example ranges from 162° to 182° (having a deviation of 20°), while the phase balance level of the third embodiment ranges from 162° to 181° (having a deviation of 19°). Accordingly, the phase balance level is improved by about 1°.

[0148] Thus, the balance levels of the third embodiment are improved over the second comparative example. The reason for this is as follows. In the second comparative example, the polarities between the IDTs 206 and 205 are the same (positive), i.e., signal electrode fingers are disposed between the IDTs 206 and 205. However, by applying withdrawal weighting in the third embodiment, the polarities between the IDTs 206 and 205 become negative and positive, as in the polarities between the IDTs 204 and 205. Thus, symmetrical characteristics of the SAW filter are improved in the third embodiment.

[0149] As described above, in the third embodiment, the electrode fingers disposed at the portion between two adjacent IDTs are withdrawal-weighted. It is thus possible to obtain a SAW filter having improved balance levels between balanced signal terminals over known SAW filters.

Fourth Embodiment

[0150] A fourth embodiment of the present invention is described in detail below with reference to Figs. 33 through 41. In the fourth embodiment, the present invention is discussed in the context of an EGSM receiving filter.

[0151] A SAW apparatus constructed in accordance with the fourth embodiment shown in Fig. 33 includes two longitudinal-coupling-resonator-type SAW filters 1918 and 1920, whose output signals are about 180° out of phase with each other. One terminal of the SAW filter 1918 and one terminal of the SAW filter 1920 are connected in parallel to each other so as to form an unbalanced signal terminal 1905, and the other terminals of the SAW filters 1918 and 1920 are connected in series to each other so as to form balanced signal terminals 1906 and 1907. With this arrangement, the SAW apparatus is provided with a balanced-to-unbalanced conversion function. Additionally, an extra longitudinal-coupling-resonator-type SAW filter 1918 is cascade-connected to each of the SAW filters 1918 and 1920, respectively. Withdrawal weighting is applied to the SAW filter 1920 by providing a dummy electrode 1901b.

[0152] In the fourth embodiment, the four longitudinal-coupling-resonator-type SAW filters 1918 and 1920 are formed by Al electrodes on a piezoelectric substrate 8. The four SAW filters 1918 and 1920 are designed similarly, except that the output signals from the SAW filters 1918 and the output signal from the SAW filter 1920 are about 180° out of phase with each other, and that the SAW filter 1920 is withdrawal-weighted. As in the third embodiment, a few narrower-pitch electrode fingers are

provided between two adjacent IDTs. The configuration of the fourth embodiment is basically similar to that of the second comparative example shown in Fig. 68, except for weighting.

[0153] When the wavelength determined by the narrower pitch of the electrode fingers is indicated by λI_2, and when the wavelength determined by the pitch of the other electrode fingers is indicated by λI_1, detailed design parameters of the SAW filter 1918 are as follows (the number in parentheses indicates the number of narrower-pitch electrode fingers):

interdigital length W: 25.2 λI_1;
number of pairs of electrode fingers of IDT 1902: 23 (4);
number of pairs of electrode fingers of IDT 1901: (4) 26(4);
number of pairs of electrode fingers of IDT 1903: 23 (4);
IDT wavelength λI_1: 4.204 μm;
IDT wavelength λI_2: 3.854 μm;
reflector wavelength λR: 4.279 μm;
number of electrode fingers of reflector: 90;
IDT pitch:

pitch between wider-pitch electrode finger (λI_1) and narrower-pitch electrode finger (λI_2) (in the same way as indicated by 215, 216, 217, and 218 in Fig.29): 0.25 λI_1 + 0.25 λI_2;
pitch between narrower-pitch electrode fingers (λI_2): 0.50 λI_2

pitch between IDT and reflector: 0.470 λR;
IDT duty ratio: 0.720
reflector duty ratio: 0.55; and
electrode thickness: 0.080 λI_1.

[0154] The feature of the fourth embodiment is that the dummy electrode 1901b is provided. More specifically, in order to invert the phase of an output signal from the SAW filter 1920 from that of the SAW filter 1918, the direction of an IDT 1901a of the SAW filter 1920 is inverted with respect to the IDT 1901 of the SAW filter 1918. One side of the IDT 1901a is withdrawal-weighted, and the dummy electrode 1901b is then provided in the weighted portion and is grounded.

[0155] The amplitude balance level between balanced signal terminals 1906 and 1907 with respect to the frequency obtained by the fourth embodiment is shown in Fig. 34. For comparison, the amplitude balance level between the balanced signal terminals with respect to the frequency in the third comparative example shown in Fig. 68 is also shown in Fig. 34. The configuration of the third comparative example is the same as that of the fourth embodiment, except that withdrawal-weighting is not applied to the second comparative example. The frequency range in the pass band used for EGSM receiving filters is 925 MHz to 960 MHz.

[0156] The amplitude balance level between the balanced signal terminals in the third comparative example ranges from -0.2 dB to +1.3 dB (having a deviation of 1.5 dB). In contrast, the amplitude balance level obtained by the fourth embodiment ranges from -0.7 dB to +0.2 dB (having a deviation of 0.9 dB). Accordingly, the amplitude balance level is improved by about 0.6 dB.

[0157] The reason for this is as follows. A SAW is excited between adjacent electrode fingers having different polarities. The excitation state of SAWs in the portions between adjacent IDTs of the SAW filters 118 and 127 (indicated by 125 and 126 in Fig. 68) shown in Fig. 68 is shown in Fig. 35.

[0158] In Fig. 35, only three electrode fingers of each IDT adjacent to another IDT are shown, and other electrode fingers are omitted. The SAW filters 118 and 127 shown in Fig. 68 correspond to longitudinal-coupling-resonator-type SAW filters 2007 and 2008, respectively, shown in Fig. 35. The IDTs 113, 114, and 115 shown in Fig. 68 correspond to IDTs 2001, 2002, and 2003, respectively, shown in Fig. 35. The IDTs 133, 134, and 135 shown in Fig. 68 correspond to IDTs 2004, 2005, and 2006, respectively, shown in Fig. 35. In Fig. 35, a SAW is excited in portions indicated by the circle, and a SAW is not excited in portions indicated by the cross (×).

[0159] In the third comparative example, in the longitudinal-coupling-resonator-type SAW filter 2007, since the outermost electrode fingers of the IDTs 2001, 2002, and 2003 are ground electrodes, a SAW is not excited between adjacent outermost electrode fingers.

[0160] In contrast, in the longitudinal-coupling-resonator-type SAW filter 2008, since an output signal of the IDT 2004 is about 180° out of phase with that of the IDT 2001 by inverting the direction of the IDT 2001, the outermost electrode fingers of the IDT 2004 are signal electrode fingers, and the outermost electrode fingers of the IDTs 2005 and 2006 are ground electrodes.

[0161] Accordingly, unlike the SAW filter 2007, in the SAW filter 2008, a SAW is excited between adjacent electrode fingers of the IDTs 2004, 2005, and 2006, and thus, there are two more portions in which a SAW is excited in the SAW filter 2008 than those of the SAW filter 2007.

[0162] In the third comparative example, therefore, the intensity distribution of the effective current of a SAW between adjacent electrode fingers becomes different between the SAW filters 2007 and 2008. As a result, in the three resonance modes shown in Fig. 72A, the period between the central resonance mode B and the highest-frequency resonance mode C becomes different between the SAW filters 2007 and 2008, thereby reducing the balance level between the balanced signal terminals.

[0163] Fig. 36 illustrates the SAW excitation state in the portions between adjacent IDTs (indicated by elliptic shapes in Fig. 33) in the SAW filters 1918 and 1920 shown in Fig. 33. As in Fig. 35, in Fig. 36, only three electrode fingers from the edge of each IDT adjacent to

another IDT are shown, and the other electrode fingers are omitted.

[0164] The SAW filters 1918 and 1920 shown in Fig. 33 correspond to SAW filters 2107 and 2108, respectively. The IDTs 1902, 1901, and 1903 of the SAW filter 1918 shown in Fig. 33 correspond to IDTs 2102, 2101, and 2103, respectively, shown in Fig. 36. The IDTs 1901a, 1902, and 1903 shown in Fig. 33 correspond to IDTs 2104, 2105, and 2106, respectively, shown in Fig. 36.

[0165] In the fourth embodiment, by inverting the direction the IDT of the SAW filter 2108 connected to the input side from that of the SAW filter 2107 connected to the input side, an output signal from the SAW filter 2107 is about 180° out of phase with that from the SAW filter 2108. The outermost electrode finger of the IDT 2104 is withdrawal-weighted, and a dummy electrode finger 2109 (the dummy electrode 1901b in Fig. 33) is then disposed in the weighted portion and is grounded.

[0166] Accordingly, in the SAW filter 2108, signal electrode fingers and ground electrode fingers are alternately disposed in a portion 2110 between the IDTs 2104 and 2105, and thus, a SAW is excited. In contrast, three ground electrode fingers are sequentially disposed in a portion 2111 between two adjacent IDTs 2104 and 2106, and thus, a SAW is not excited in two portions.

[0167] As a result, the total number of portions in which a SAW is not excited in the SAW filter 2107 is the same as that in the SAW filter 2108. In other words, the total number of portions in which a SAW is excited in the SAW filter 2107 is equal to that in the SAW filter 2108. Thus, the period of appearance of the resonance modes is smaller than that of the third comparative example, thereby improving the amplitude balance level between the balanced signal terminals.

[0168] As an example of a modification of the fourth embodiment, a SAW apparatus shown in Fig. 37 includes a first longitudinal-coupling-resonator-type SAW filter unit 2202 and a second longitudinal-coupling-resonator-type SAW filter unit 2204. The first SAW filter unit 2202 is formed by cascade-connecting two longitudinal-coupling-resonator-type SAW filters 2201. The second SAW filter unit 2202 is formed by cascade-connecting the longitudinal-coupling-resonator-type SAW filter 2201 and a longitudinal-coupling-resonator-type SAW filter 2201a. The direction of an IDT 2203 of the SAW filter 2201a is inverted with respect to that of the corresponding IDT of the SAW filter 2201. Accordingly, an output signal from the SAW filter unit 2202 is about 180° out of phase with an output signal from the SAW filter unit 2204. The central IDTs of the first stage of SAW filters 2201 are connected in parallel to each other to form an unbalanced signal terminal 2205. The central IDTs of the second stage of the SAW filters 2201 and 2201a are connected in series to each other so as to form balanced signal terminals 2206.

[0169] As in the fourth embodiment, with this modification, the outermost electrode finger of the IDT 2203 is withdrawal-weighted, and a dummy electrode 2207 is then provided in the weighted portion and is grounded. The SAW excitation state in the portion between two adjacent IDTs (indicated by the elliptical shapes in Fig. 37) in the first and second SAW filter units 2202 and 2204 connected to the balanced signal terminals 2206 is shown in Fig. 38. The total number of portions between electrode fingers in which a SAW is not excited in the SAW filter unit 2202 is equal to that in the SAW filter unit 2204. Thus, the amplitude balance level between the balanced signal terminals 2206 can be improved.

[0170] As shown in Fig. 39, instead of inverting the central IDT of the second stage of the SAW filter, the direction of the external IDTs may be inverted, and thus, an output signal from a first SAW filter unit 2303 is about 180° out of phase with an output signal from a second SAW filter unit 2304.

[0171] As in the fourth embodiment, with this modification, the outermost electrode finger of an inverted IDT 2301 is withdrawal-weighted, and a dummy electrode 2302 is then provided in the weighted portion and is grounded. In this case, the SAW excitation state of the portions between two adjacent IDTs (indicated by the elliptical shapes in Fig. 39) in the SAW filter connected to the balanced signal terminals is shown in Fig. 40. As shown in Fig. 40, the total number of portions between electrode fingers in which a SAW is not excited in the first SAW filter unit 2303 is equal to that in the second SAW filter unit 2304. As a result, the amplitude balance level between the balanced signal terminals can be improved.

[0172] Instead of the three-IDT-type longitudinal-coupling-resonator-type filters shown in Fig. 33, five-IDT-type longitudinal-coupling-resonator-type filters may be used, as shown in Fig. 41. In this case, one of the outermost electrode finger of an inverted IDT 2401 is withdrawal-weighted, and a dummy electrode finger 2402 is then disposed in the weighted portion and is grounded. Thus, the total number of portions between electrode fingers in which a SAW is not excited in a first SAW filter unit 2403 is the same as that in a second SAW filter unit 2404. Thus, the amplitude balance level between the balanced signal terminals can be improved.

[0173] As described above, according to the SAW apparatus of the fourth embodiment, two SAW filters whose output signals are about 180° out of phase with each other, and one signal terminal of one SAW filter and one signal terminal of the other SAW filter are connected in series to each other to form balanced signal terminals, while the other signal terminals of the two SAW filters are connected in parallel to each other to form an unbalanced signal terminal. With this arrangement, the SAW apparatus is provided with a balanced-to-unbalanced conversion function. Moreover, an additional SAW filter is cascade-connected to each of the two SAW filters, and then, withdrawal-weighting is applied to the cascade-connected SAW filter. As a result, it is possible to obtain a SAW apparatus having im-

proved balance levels between balanced signal terminals over known SAW apparatuses.

Fifth Embodiment

[0174] A fifth embodiment of the present invention is discussed below with reference to Figs. 42 through 46. In the fifth embodiment, the present invention is described in the context of a Digital Cellular System (DCS) receiving filter.

[0175] A SAW apparatus constructed in accordance with the fifth embodiment of the present invention is shown in Fig. 42. Two longitudinal-coupling-resonator-type SAW filters whose output signals are about 180° out of phase with each other are provided. One terminal of one SAW filter and one terminal of the other SAW filter are connected in series to each other so as to form balanced signal terminals, while the other terminals of the SAW filters are connected in parallel to each other so as to form an unbalanced signal terminal. Accordingly, the SAW apparatus is provided with a balanced-to-unbalanced conversion function. Weighting is applied to this configuration.

[0176] In the fifth embodiment, longitudinal-coupling-resonator-type SAW filters 2501 and 2508 and SAW resonators 2502 and 2503 are formed by Al electrodes on the above-described piezoelectric substrate 8. The SAW resonators 2502 and 2503 are connected in series to each of the SAW filters 2501 and 2508. The two SAW filters 2501 and 2508 are designed similarly, except that an output signal from the SAW filter 2501 is about 180° out of phase with that from the SAW filter 2508. As in the third embodiment, in the fifth embodiment, a few narrower-pitch electrode fingers are provided between two IDTs.

[0177] When the wavelength determined by the narrower pitch of the electrode fingers is indicated by λI_2, and when the wavelength determined by the pitch of the other electrode fingers is indicated by λI_1, detailed design parameters of the SAW filters 2501 and 2508 are as follows (the number in parentheses indicates the number of narrower-pitch electrode fingers):

interdigital length W: 37.12 λI_1;
number of pairs of electrode fingers of IDT 2504: (4) 19;
number of pairs of electrode fingers of IDT 2505: (4) 31(4);
number of pairs of electrode fingers of IDT 2506: 19 (4);
IDT wavelength λI_1: 2.156 μm;
IDT wavelength λI_2: 1.926 μm;
reflector wavelength λR: 2.177 μm;
number of electrode fingers of reflector: 150;
IDT pitch:

pitch between wider-pitch electrode finger (λI_1) and narrower-pitch electrode finger (λI_2): 0.25 λI_1 + 0.25 λI_2;
pitch between narrower-pitch electrode fingers (λI_2): 0.50 λI_2;

pitch between IDT and reflector: 0.50 λR;
IDT duty ratio: 0.63;
reflector duty ratio: 0.60; and
electrode thickness: 0.09 λI_1.

[0178] Detailed design parameters of the SAW resonator 2502 are as follows:

interdigital length W: 14.3 λI;
number of pairs of electrode fingers of IDT: 241;
wavelength λ (for IDT and reflectors): 2.102 μm;
number of electrode fingers of reflectors: 30; and
pitch between IDT and reflector: 0.50 λR.

[0179] Detailed design parameters of the SAW resonator 2503 are as follows:

interdigital length W: 37.1 λI;
number of pairs of electrode fingers of IDT: 241;
wavelength λ (for IDT and reflectors): 2.023 μm;
number of electrode fingers of reflector: 30; and
pitch between IDT and reflector: 0.50 λR.

[0180] The features of the fifth embodiment are as follows. In order to invert the phase of an output signal from the SAW filter 2508 with respect to that from the SAW filter 2501, the direction of an IDT 2509 of the SAW filter 2508 is inverted, and one of the outermost signal electrode fingers of the IDT 2509 is withdrawal-weighted, and a dummy electrode 2510 is then provided in the weighted portion and is grounded. Additionally, the three IDTs are grounded via the dummy electrode 2510.

[0181] Fig. 43 illustrates the amplitude balance level between the balanced signal terminals with respect to the frequency obtained by the fifth embodiment. For comparison, the amplitude balance level between balanced signal terminals in a fourth comparative example shown in Fig. 44 is also shown in Fig. 43. The configuration of the fourth comparative example shown in Fig. 44 is the same as that of the fifth embodiment, except that withdrawal-weighting is not applied to the fourth comparative example.

[0182] The frequency range of the pass band used for DCS receiving filters is 1805 MHz to 1880 MHz. The amplitude balance level between the balanced signal terminals in this range in the fourth comparative example ranges from -1.0 dB to +3.2 dB (having a deviation of 4.2 dB), while the corresponding amplitude balance level obtained by the fifth embodiment ranges from -0.5 dB to +1.5 dB (having a deviation of 2.0 dB). Thus, the amplitude balance level is improved by about 2.2 dB.

[0183] The reason for this is as follows. The number of portions between adjacent IDTs in which a SAW is excited (indicated by the elliptical shapes in Fig. 44) in

the fourth comparative example shown in Fig. 44 is different between a first SAW filter 2601 and a second SAW filter 2602, as shown in Fig. 45. In contrast, as shown in Fig. 46, the number of portions between adjacent IDTs in which a SAW is excited (indicated by the elliptical shapes in Fig. 42) is the same between first and second longitudinal-coupling-resonator-type SAW filter unit 2511 and 2512. Thus, in the three resonance modes shown in Fig. 72A, the periods between the central resonance mode B and the highest-frequency resonance mode C between the signals output from the two balanced signal terminals becomes closer than the third comparative example.

[0184] As described above, in the fifth embodiment, the SAW apparatus includes two longitudinal-coupling-resonator-type SAW filters whose output signals are about 180° out of phase with each other. One signal terminal of one SAW filter and one signal terminal of the other SAW filter are connected in series to each other to form balanced signal terminals, and the other signal terminals of the two SAW filters are connected in parallel to each other to form an unbalanced signal terminal. With this configuration, the SAW apparatus is provided with a balanced-to-unbalanced conversion function. Withdrawal-weighting is applied to this configuration. It is thus possible to obtain a SAW apparatus having improved balanced levels between the balanced signal terminals over known SAW apparatuses.

[0185] The three IDTs including the dummy electrode 2510 are grounded, thereby strengthening a grounding force of the SAW apparatus. Accordingly, the insertion loss within the pass band can be decreased, and the attenuation outside the pass band can be improved. The ground terminal of the central IDT may be omitted. Sixth Embodiment

[0186] A sixth embodiment of the present invention is described below with reference to Figs. 47 through 54. In the sixth embodiment, the present invention is discussed in the context of a DCS receiving filter.

[0187] As in the third embodiment, in the sixth embodiment, balanced signal terminals 2711 and 2712 are connected to comb-like electrodes of an IDT 2704 of a single longitudinal-coupling-resonator-type SAW filter 2701. Weighting is then applied to the configuration of a SAW apparatus without an electrical neutral point.

[0188] In the sixth embodiment, the longitudinal-coupling-resonator-type SAW filter 2701, and SAW resonators 2702 and 2703, which are connected in series to the SAW filter 2701, are formed by Al electrodes on the above-described piezoelectric substrate 8.

[0189] The configuration of the SAW filter 2701 is as follows. IDTs 2705 and 2706 are disposed on the left and right sides of the IDT 2704, and reflectors 2707 and 2708 are disposed such that they sandwich the IDTs 2705, 2704, and 2706 therebetween.

[0190] As in the third embodiment, in the sixth embodiment, a few narrower-pitch electrode fingers are disposed in portions between two adjacent IDTs (indicated by 2709 and 2710 in Fig. 47). Reference numeral 2713 designates an unbalanced signal terminal. An enlarged view of the portion between the IDTs 2704 and 2705 is shown in Fig. 48.

[0191] An outer electrode finger 2704a of the IDT 2704 connected to the balanced signal terminal 2711 is apodization-weighted, a dummy electrode 2705a is then provided in the weighted portion and is grounded.

[0192] When the wavelength determined by the narrower pitch of the electrode fingers is indicated by λI_2, and when the wavelength determined by the pitch of the other electrode fingers is indicated by λI_1, detailed design parameters of the SAW filter 2701 are as follows (the number in parentheses indicates the number of narrower-pitch electrode fingers):

- interdigital length:
  - no-apodization-weighted portion (indicated by 2805 in Fig. 48): 71.2 λI_1;
  - apodization-weighted portion (indicated by 2806 in Fig. 48: 35.6 λI_1;
- number of pairs of electrode fingers of IDT 2705: 21 (4);
- number of pairs of electrode fingers of IDT 2704: (4) 35(4);
- number of pairs of electrode fingers of IDT 2706: (4) 21;
- IDT wavelength λI_1: 2.18 μm;
- IDT wavelength λI_2: 1.96 μm;
- reflector wavelength λR: 2.18 μm;
- number of electrode fingers of reflector: 150;
- IDT pitch:
  - pitch between wider-pitch electrode finger (λI_1) and narrower-pitch electrode finger (λI_2) (indicated by 2714 in Fig. 47): 0.25 λI_1 + 0.25 λI_2;
  - pitch between narrower-pitch electrode fingers (λI_2) (indicated by 2715 in Figs. 47 and 48): 0.50 λI_2;
- pitch between IDT and reflector: 0.460 λR;
- IDT duty ratio:
  - wider-pitch portion: 0.63;
  - narrower-pitch portion: 0.60;
- reflector duty ratio: 0.57; and
- electrode thickness: 0.09 λI_1.

[0193] Detailed design parameters of the SAW resonator 2702 are as follows:

- interdigital length W: 23.6 λI;
- number of pairs of electrode fingers of IDT: 241;
- wavelength (for IDT and reflectors): 2.12 μm;

number of electrode fingers of reflectors: 30; and
pitch between IDT and reflector: 0.50 λR.

[0194] Detailed design parameters of the SAW resonator 2703 are as follows:

interdigital length W: 58.5 λI;
number of pairs of electrode fingers of IDT: 241;
wavelength (for IDT and reflectors): 2.04 μm;
number of electrode fingers of reflector: 30; and
pitch between IDT and reflector: 0.50 λR.

[0195] The features of the sixth embodiment are as follows. Apodization weighting is applied to the outermost electrode fingers of the central IDT 2704 which is adjacent to the ground electrode fingers and which is connected to the balanced signal terminal 2711 so as to form the apodization-weighted electrode fingers 2704a. The dummy electrode 2705a and a dummy electrode 2706a are then disposed in the apodization-weighted portions, and are grounded.

[0196] The operations and advantages of the sixth embodiment are as follows. The amplitude balance level between the balanced signal terminals 2711 and 2712 with respect to the frequency obtained by the sixth embodiment is shown in Fig. 49. For comparison, the amplitude balance level between balanced signal terminals with respect to the frequency in a fifth comparative example shown in Fig. 50 is also shown in Fig. 49. The configuration of the fifth comparative example is the same as that of the sixth embodiment, except in the configuration of a longitudinal-coupling-resonator-type SAW filter 2701a, and more specifically, apodization weighting is not applied to outermost electrode fingers of a central IDT. The frequency range of the pass band used for DCS receiving filters is 1805 MHz to 1880 MHz.

[0197] The amplitude balance level in this range in the fifth comparative example ranges from -1.3 dB to +3.3 dB (having a deviation of 4.6 dB), while the corresponding amplitude balance level obtained by the sixth embodiment ranges from -2.0 dB to +1.9 dB (having a deviation of 3.9 dB). Thus, the amplitude balance level is improved by about 0.7 dB.

[0198] In the fifth comparative example, the amplitude balance level is deviated considerably toward the positive side, while the deviation of the sixth embodiment is almost equal between the positive side and the negative side. If the amplitude balance level is deviated almost equally between the positive side and the negative side, as in the sixth embodiment, the noise level of an in-phase signal advantageously becomes smaller. Thus, the sixth embodiment exhibits excellent characteristics over the fifth comparative example in this respect.

[0199] The above-described advantages can be achieved by the sixth embodiment due to the following reason. Apodization weighting is applied to the outermost electrode fingers of the central IDT 2704, the dummy electrodes 2705a and 2706a are then disposed in the weighted portions and are grounded. With this arrangement, the outermost electrode fingers of the IDT 2704 connected to the balanced signal terminals 2711 and 2712 are disposed adjacent to the ground electrode fingers, and thus, the polarities of the outermost electrode fingers between adjacent IDTs become equal in the left and right sides of the SAW apparatus.

[0200] The apodization-weighting optimal value was checked, and the results are given below. In this checking, in the configuration shown in Figs. 47 and 48, the ratio of the interdigital length 2806 to which apodization weighting is applied to the interdigital length 2805 to which apodization weighting is not applied (hereinafter this ratio is referred to as the "apodization-weighting ratio") was varied, and the a change in the amplitude balance level between the balanced signal terminals within the pass band was examined.

[0201] In this case, the apodization-weighting ratio in the configuration shown in Fig. 50 to which apodization weighting is not applied was set to be 1, and the apodization-weighting ratio in the configuration shown in Fig. 47 was set to 1/2. Then, the amplitude balance level between the balanced signal terminals was checked by varying the apodization-weighting ratio to 1/4, 1/2, and 3/4. The results are shown in Fig. 51. In Fig. 51, the amplitude balance level is shown only in the positive side.

[0202] Fig. 51 reveals that the amplitude balance level within the pass band becomes minimum when the apodization-weighting ratio is about 0.5, i.e., when apodization weighting is applied substantially at the center of the electrode finger. The reason for this is as follows. The outermost electrode fingers of the central IDT are weighted substantially at the center of the interdigital length, and the weighted electrode fingers are grounded. Thus, the outermost electrode fingers of the IDT connected to the balanced signal terminals 2711 and 2712 are located adjacent to the ground electrodes by half the interdigital length. Thus, the polarities of the electrode fingers between adjacent IDTs become equal between the left and right sides of the SAW apparatus.

[0203] As described above, the configuration of the sixth embodiment is as follows. Balanced signal terminals are connected to comb-like electrodes of an IDT (preferably, the central IDT) of a single longitudinal-coupling-resonator-type SAW filter, and thus, this configuration does not have an electrical neutral point. In this configuration, apodization-weighting is applied to the outermost electrode fingers of the central IDT substantially at the center of the interdigital length, and dummy electrodes are then disposed in the weighted portions and are grounded. As a result, a SAW apparatus having an improved amplitude balance level between balanced signal terminals over known SAW apparatuses can be obtained.

[0204] In the sixth embodiment, the outermost electrode fingers of the central IDT connected to the balanced signal terminals are adjacent to ground electrode fingers. Alternatively, as shown in Fig. 52, one outer-

most electrode finger of the central IDT may be connected to a ground electrode finger, and the other outermost electrode finger of the central IDT may be connected to a signal electrode finger. In this case, apodization weighting is applied to only the signal electrode finger adjacent to the ground electrode finger, and a dummy electrode is then disposed in the weighted portion and is grounded via the IDT. With this modification, as in the sixth embodiment, a SAW apparatus having an improved amplitude balance level between balanced signal terminals can be obtained.

[0205] Alternatively, as shown in Fig. 53, in the configuration in which balanced signal terminals 2711 and 2712 are connected to two IDTs, apodization weighting is applied to the outermost electrode fingers of each IDT, and the weighted electrode fingers are grounded via the corresponding IDT and reflectors. With this modification, as in the sixth embodiment, the amplitude balance level between the balanced signal terminals 2711 and 2712 can be improved.

[0206] Although in the sixth embodiment a three-IDT-type longitudinal-coupling-resonator-type SAW filter is used, a longitudinal-coupling-resonator-type SAW filter having four or more IDTs may be used. For example, in the configuration shown in Fig. 54, apodization weighting is applied to the electrode fingers of IDTs connected to balanced signal terminals 2711 and 2712, and dummy electrodes are disposed and are rounded via the corresponding IDTs. With this modification, as in the sixth embodiment, the amplitude balance levels between the balanced signal terminals 2711 and 2712 can be improved. Seventh Embodiment

[0207] A seventh embodiment of the present invention is described below with reference to Figs. 55 through 61. In the seventh embodiment, the present invention is discussed in the context of a PCS receiving filter.

[0208] As in the third embodiment, in the seventh embodiment, balanced signal terminals 2910 and 2911 are connected to comb-like electrodes of an IDT 2905 of a single longitudinal-coupling-resonator-type SAW filter 2901. Weighting is then applied to the configuration of a SAW apparatus without an electrical neutral point.

[0209] In the seventh embodiment, the longitudinal-coupling-resonator-type SAW filter 2901, and SAW resonators 2902 and 2903, which are connected in series to the SAW filter 2901, are formed by Al electrodes on the above-described piezoelectric substrate 8. The configuration of the seventh embodiment is basically similar to that of the third embodiment shown in Fig. 29.

[0210] The features of the seventh embodiment are as follows. The duty ratio of electrode fingers 2919 and 2920 is set to 0.40. Additionally, a grounded shield line 2921 is inserted between a signal line 2912 and the balanced signal terminal 2910. By inserting a grounded shield line between adjacent signal electrode fingers, the bridge capacitance between the signal electrodes fingers can be reduced. Thus, a SAW apparatus having further improved balance levels can be obtained.

[0211] The operations and advantages of the seventh embodiment are as follows. Figs. 56 and 57 illustrate the amplitude balance level and the phase balance level, respectively, between the balanced signal terminals 2910 and 2911 obtained by the seventh embodiment. For comparison, the amplitude balance level and the phase balance level between the balanced signal terminals in the second comparative example shown in Fig. 32 are also shown in Figs. 56 and 57, respectively. The configuration of the second comparative example shown in Fig. 32 is the same as that of the seventh embodiment, except that the duty ratio of the outermost electrode fingers of the central IDT (corresponding to 2919 and 2920 in Fig. 55) are not changed. The frequency range in the pass band used for PCS receiving filters is 1930 MHz to 1990 MHz.

[0212] No substantial difference can be observed in the deviation in the phase balance level in this range between the seventh embodiment and the second comparative example. However, the amplitude balance level in the second comparative example ranges from -0.5 dB to +2.3 dB (having a deviation of 2.8 dB), while the amplitude balance level in the seventh embodiment ranges from -0.6 dB to +2.0 dB (having a deviation of 2.6 dB). Thus, the amplitude balance level is improved by about 0.2 dB.

[0213] Additionally, the amplitude balance level is deviated considerably toward the positive side in the second comparative example, while a difference in the deviation between the positive side and the negative side is smaller in the seventh embodiment. With a smaller difference in the deviation between the positive side and the negative side, as in the seventh embodiment, the noise level of an in-phase signal advantageously becomes smaller. Thus, the seventh embodiment exhibits excellent characteristics over the second comparative example in this respect.

[0214] The above-described advantages can be achieved by the seventh embodiment due to the following reason. The duty ratio of the electrode fingers 2919 and 2920 of the IDT 2905 adjacent to IDTs 2904 and 2906, respectively, is set to be smaller than that of the other electrode fingers. Accordingly, a difference in the total capacitance of the electrode fingers connected to the balanced signal terminals 2910 and 2911, and a difference in the conversion efficiency between an electrical signal and a SAW between the left and right sides of the SAW apparatus can be offset.

[0215] The difference in the total capacitance of the electrode fingers on the left and right sides is particularly noticeable in the portions between two adjacent IDTs. Thus, by adjusting the duty ratio of these portions, the difference in the total capacitance becomes smaller. To further enhance this effect, as shown in Fig. 58, the duty ratio of a few electrode fingers 2919 and 2920 positioned adjacent to the portions between two IDTs may be adjusted.

[0216] As a modification of the seventh embodiment, as shown in Fig. 59, the duty ratio of an electrode finger 3001 of an IDT 2904a adjacent to an IDT 2905b and the duty ratio of an electrode finger 3002 of an IDT 2906a adjacent to the IDT 2905b are set to be smaller than that of the other electrode fingers. Then, the amplitude balance level and the phase balance level between balanced signal terminals 2910 and 2911 with respect to the frequency are shown in Figs. 60 and 61, respectively. In this case, the duty ratio of the electrode fingers 3001 and 3002 is set to be 0.40.

[0217] For comparison, the amplitude balance level and the phase balance level between the balanced signal terminals in the second comparative example shown in Fig. 32 are also shown in Figs. 60 and 61, respectively. No substantial difference can be observed in the deviation of the phase balance level in this range between the second comparative example and this modification. However, the amplitude balance level of the second comparative example ranges from -0.5 dB to +2.3 dB (having a deviation of 2.8 dB), while the amplitude balance level of the modification of the seventh embodiment ranges from -0.5 dB to +2.0 dB (having a deviation of 2.5 dB). Thus, the amplitude balance level is improved by about 0.3 dB.

[0218] As discussed above, by adjusting the duty ratio of electrode fingers of the IDTs connected to an unbalanced signal terminal, such as the configuration shown in Fig. 59, the advantages of the present invention can also be obtained. In addition to the electrode fingers 3001 and 3002, the duty ratio of the IDT 2905b may also be adjusted, in which case, the advantages of the present invention can be achieved.

[0219] According to the foregoing description, in the seventh embodiment, the balanced signal terminals are connected to the comb-like electrodes of an IDT of a single longitudinal-coupling-resonator-type SAW filter. Accordingly, this configuration does not have an electrical neutral point. Then, duty ratio weighting is applied to part of the IDT, in particular, to the portions between two adjacent IDTs. It is thus possible to obtain a SAW apparatus having improved amplitude balance levels between balanced signal terminals over known SAW apparatuses. Eighth Embodiment

[0220] An eighth embodiment of the present invention is described below with reference to Figs. 62 through 64. In the configuration of the eighth embodiment shown in Fig. 62, not only the duty ratio of the outermost electrode fingers of an IDT 2905c adjacent to IDTs 2904 and 2906, but also the duty ratio of all the electrode fingers of the IDT 2905c connected to a balanced signal terminal 2910 is set to be a value smaller than the other electrode fingers, for example, to 0.40. The configuration of the eighth embodiment is the same as that of the seventh embodiment, except for this feature.

[0221] The operations and advantages of the eighth embodiment are as follows. The amplitude balance level and the phase balance level between balanced signal terminals 2910 and 2911 with respect to the frequency obtained by the eighth embodiment are shown in Figs. 63 and 64, respectively. For comparison, the amplitude balance level and the phase balance level between the balanced signal terminals in the second comparative example shown in Fig. 32 are also shown in Figs. 63 and 64, respectively. The phase balance level in the frequency range of the pass band for PCS receiving filters in the eighth embodiment is slightly reduced than the second comparative example. However, the amplitude balance level of the eighth embodiment is improved over the second comparative example by about 0.5 dB.

[0222] Additionally, in the second comparative example, the amplitude balance level is deviated toward the positive side. In the eighth embodiment, however, the difference in the deviation in the phase balance level between the positive side and the negative side is smaller. With a smaller difference in the deviation between the positive side and the negative side, as in the eighth embodiment, the noise level of an in-phase signal is advantageously smaller. Thus, the eight embodiment exhibits excellent characteristics over the second comparative example in this respect.

[0223] According to the foregoing description, in the eighth embodiment, balanced signal terminals 2910 and 2911 are connected to the comb-like electrodes of the IDT 2905c of a single longitudinal-coupling-resonator-type SAW filter. Accordingly, this configuration does not have an electrical neutral point. Then, duty ratio weighting is applied to all the electrode fingers connected to one of the balanced signal terminals. It is thus possible to obtain a SAW apparatus having improved amplitude balance levels between balanced signal terminals over known SAW apparatuses.

[0224] When the duty ratio of all the electrode fingers of the IDT 2905c connected to the balanced signal terminal 2910 is adjusted, as shown in Fig. 62, the amplitude balance level is further improved, but the phase balance level is reduced. However, by adjusting the duty ratio of the required number of electrode fingers, as shown in Figs. 55 and 58, or by changing the duty ratio among the electrode fingers, the amplitude balance level can be improved without reducing the phase balance level.

Ninth Embodiment

[0225] A ninth embodiment of the present invention is described below with reference to Fig. 65. The configuration of the ninth embodiment is basically similar to that of the seventh embodiment. In the ninth embodiment, however, the duty ratio of an electrode finger 3003 of an IDT 2905d adjacent to an IDT 2904 is set to be smaller, and the outermost signal electrode finger of an IDT 2906b adjacent to the IDT 2905d is withdrawal-weighted, and a grounded dummy electrode 3004 is then disposed in the weighted portion.

[0226] The operations and advantages of the ninth

embodiment are as follows. As discussed above, by applying two or more types of weighting methods to a single longitudinal-coupling-resonator-type SAW filter, the flexibility in adjusting the balance levels between balanced signal terminals is increased. Thus, a SAW apparatus having a desired balance level can be obtained.

[0227] In the foregoing embodiments, a 40±5° Y-cut X-propagating $LiTaO_3$ substrate is used as the piezoelectric substrate. However, as is seen from the principle of the present invention, another type of substrate, such as a 64-72° Y-cut X-propagating $LiNbO_3$ substrate or a 41° Y-cut X-propagating $LiNbO_3$ substrate, may be used, in which case, advantages similar to those obtained by the above-described embodiments can be achieved.

[0228] In a SAW apparatus formed of two SAW filters, each having three or more IDTs, it is preferable that weighting be applied to the electrode fingers of the SAW filters so as to strengthen the excitation of a SAW. With this arrangement, the amplitude balance level within the pass band can be improved without decreasing the pass bandwidth.

[0229] Weighting may be applied, for example, as follows, so as to strengthen the excitation of a SAW. Withdrawal weighting, apodization weighting (including the formation of a dummy electrode), or more preferably, series weighting, is applied to the outermost electrode fingers (more preferably, to signal electrode fingers) of a central IDT of one SAW filter without applying weighting to the other SAW filter.

[0230] Various types of weighting have been discussed in the foregoing embodiments, and each type of weighting offers individual operations and advantages. Thus, the advantages of the present invention can be achieved by any combination of two or more weighting types.

[0231] A description is now given, with reference to Fig. 66, of a communications unit using the SAW filter apparatus of one of the first through ninth embodiments of the present invention.

[0232] In a communications unit 3100, as shown in Fig. 66, on which the SAW apparatus of one of the foregoing embodiments is mounted, a receiver (Rx) includes an antenna 3101, an antenna duplexer/RF top filter 3102, an amplifier 3103, an Rx interstage filter 3104, a mixer 3105, a first IF filter 3106, a mixer 3107, a second IF filter 3108, a first-and-second-signal local synthesizer 3111, a temperature compensated crystal oscillator (TCXO) 3112, a divider 3113, and a local filter 3114. As indicated by two lines between the Rx interstage filter 3104 and the mixer 3105 shown in Fig. 66, two balanced signals are preferably transmitted from the Rx interstage filter 3104 to the mixer 3105 in order to maintain the balance levels.

[0233] In the communications unit 3100, a transmitter (Tx) includes the antenna 3101, the antenna duplexer/RF top filter 3102, a Tx IF filter 3121, a mixer 3122, a Tx interstage filter 3123, an amplifier 3124, a coupler 3125, an isolator 3126, and an automatic power control (APC) device 3127. The antenna 3101 and the antenna duplexer/RF top filter 3102 are shared by the receiver (Rx) and the transmitter (Tx).

[0234] The SAW filter apparatus of any one of the first through ninth embodiments is suitably used as the Rx interstage filter 3104.

[0235] The communications unit 3100 uses the smaller SAW apparatus exhibiting excellent transmission characteristics. Accordingly, the size of the communications unit 3100 can also be reduced, particularly in a GHz band or higher, while exhibiting a high level of transmission characteristics.

[0236] Although the present invention has been described in terms of specific preferred embodiments thereof, it is to be understood that various modifications may be made therein within the scope of the appended claims.

Claims

1. A surface acoustic wave apparatus comprising:

    at least one surface acoustic wave filter including at least two interdigital transducers (1-3) formed on a piezoelectric substrate (8) in a direction in which a surface acoustic wave propagates; and

    an input signal terminal (5/6,7) and an output signal terminal (6,7/5) for said at least one surface acoustic wave filter,

    wherein at least one (6/7) of said input signal terminal and said output signal terminal is connected to a balanced signal terminal, and weighting is applied to at least part (22,32) of electrode fingers of said at least one surface acoustic wave filter.

2. A surface acoustic wave apparatus according to claim 1, wherein the weighting is applied to said at least part (22,32) of the electrode fingers so as to improve at least one of an amplitude balance level and a phase balance level between a pair of the balanced signal terminals.

3. A surface acoustic wave apparatus according to claim 1 or 2, wherein the weighting is applied to a few of the electrode fingers counted from an outermost electrode finger of at least one of the interdigital transducers located adjacent to another interdigital transducer.

4. A surface acoustic wave apparatus according to claim 1 or 2, wherein the weighting is applied to a few of the electrode fingers in the vicinity of an outermost electrode finger of at least one of the interdigital transducers located adjacent to another in-

terdigital transducer.

5. A surface acoustic wave apparatus according to claim 1 or 2, wherein the weighting is applied to the electrode fingers located within 1/2 length of one interdigital transducer in the propagating direction of the surface acoustic wave from an outermost electrode finger of at least one of the interdigital transducers located adjacent to another interdigital transducer.

6. A surface acoustic wave apparatus according to claim 1 or 2, wherein the weighting is applied to an outermost electrode finger of at least one of the interdigital transducers adjacent to another interdigital transducer.

7. A surface acoustic wave apparatus according to claim 1 or 2, wherein the electrode fingers located in a portion between the adjacent interdigital transducers are a ground electrode finger and a signal electrode finger, and the weighting is applied to at least one of the ground electrode finger and the signal electrode finger.

8. A surface acoustic wave apparatus according to any previous claim, wherein the weighting is applied to a signal electrode finger of said surface acoustic wave filter.

9. A surface acoustic wave apparatus according to any previous claim, wherein the weighting is applied to at least part (22,32) of the electrode fingers of the interdigital transducer connected to the balanced signal terminal (6,7) of said surface acoustic wave filter.

10. A surface acoustic wave apparatus according to any previous claim 1, wherein the phase of at least one of the interdigital transducers is inverted with respect to the phase of the other interdigital transducer(s), and the weighting is applied to at least part of the electrode fingers of the phase-inverted interdigital transducer.

11. A surface acoustic wave apparatus according to any previous claim, wherein the weighting is withdrawal weighting.

12. A surface acoustic wave apparatus according to claim 11, wherein a dummy electrode (31a) is provided for a bus bar (33) which faces a bus bar (34) connected to the withdrawal-weighted electrode finger.

13. A surface acoustic wave apparatus according to claim 1 or 2, wherein the weighting is applied to at least two continuous ground electrode fingers including an outermost electrode finger of at least one of the interdigital transducer connected to said input signal terminal (5/6,7) and the interdigital transducer connected to said output signal (6,7/5) terminal, the ground electrode fingers being located such that it faces the other interdigital transducer.

14. A surface acoustic wave apparatus according to claim 12, wherein a ground connecting portion is arranged for connecting the electrode fingers of the adjacent interdigital transducers which are connected to ground via a dummy electrode.

15. A surface acoustic wave apparatus according to any previous claim, wherein the weighting is apodization weighting in which an interdigital length of at least part (22a) of the electrode fingers is differentiated from an interdigital length of the other electrode fingers.

16. A surface acoustic wave apparatus according to any previous claim, wherein the weighting is applied to part (22a) of the electrode fingers such that they are set to be shorter than the other electrode fingers.

17. A surface acoustic wave apparatus according to claim 15, wherein the apodization weighting is applied substantially at the center of the interdigital length.

18. A surface acoustic wave apparatus according to claim 15, wherein the apodization weighting is further applied to the electrode finger (21b) adjacent to the apodization-weighted electrode finger (22a), and a bending dummy electrode (25a) is disposed such that it faces each of the two apodization-weighted electrode fingers.

19. A surface acoustic wave apparatus according to claim 15, wherein the apodization-weighted electrode finger (22a) is an outermost electrode finger of one of the adjacent interdigital transducers (2), and a dummy electrode is provided for the other interdigital transducer such that the dummy electrode faces the apodization-weighted electrode finger (Fig.52).

20. A surface acoustic wave apparatus according to claim 19, wherein the dummy electrode is grounded.

21. A surface acoustic wave apparatus according to any previous claim, wherein the weighting is duty ratio weighting in which a duty ratio of at least part of the electrode fingers is differentiated from a duty ratio of the other electrode fingers.

22. A surface acoustic wave apparatus according to claim 1 or 2, wherein said surface acoustic wave filter includes at least three interdigital transducers (1-3), and withdrawal-weighting is applied to at least one (3) of the adjacent interdigital transducers, and the weighting applied to the interdigital transducer (2) on one side of said surface acoustic wave filter is different from the weighting applied to the interdigital transducer (3) on the other side of said surface acoustic wave filter.

23. A surface acoustic wave apparatus according to claim 1 or 2, wherein two (1104,1105) of said surface acoustic wave filters are provided, and withdrawal-weighting is applied to each of said surface acoustic wave filters, and the weighting applied to one (1104) of the surface acoustic wave filters is different from the weighting applied to the other surface acoustic wave filter (1105).

24. A surface acoustic wave apparatus according to claim 1 or 2, wherein said surface acoustic wave filter comprises at least three adjacent interdigital transducers (1-3), in which apodization-weighting is applied to a few of the electrode fingers other than an outermost electrode finger of at least one of the adjacent interdigital transducers (2) on one side of said surface acoustic wave filter, and withdrawal-weighting is applied to an outermost electrode finger of at least one of the adjacent interdigital transducers (3) on the other side of said surface acoustic wave filter, a dummy electrode (31 a) connected to a bus bar (33) which faces a bus bar (34) connected to the withdrawal-weighted electrode finger being disposed in the withdrawal-weighted portion.

25. A surface acoustic wave apparatus according to claim 1 or 2, wherein said surface acoustic wave filter comprises at least three of the adjacent interdigital transducers (1-3), in which duty-ratio-weighting is applied to an outermost electrode finger of at least one of the adjacent interdigital transducers (2) on one side of said surface acoustic wave filter so that a duty ratio of the outermost electrode finger is differentiated from a duty ratio of the other electrode fingers, and withdrawal-weighting is applied to an outermost electrode finger of at least one of the adjacent interdigital transducers (3) on the other side of said surface acoustic wave filter, a dummy electrode (31a) connected to a bus bar (33) which faces a bus bar (34) connected to the withdrawal-weighted electrode finger being disposed in the withdrawal-weighted portion.

26. A surface acoustic wave apparatus according to claim 1 or 2, wherein two of said surface acoustic wave filters are provided, in which apodization-weighting is applied to a few of the electrode fingers other than an outermost electrode finger of at least one of the adjacent interdigital transducers of one of the surface acoustic wave filters, and withdrawal-weighting is applied to an outermost electrode finger of at least one of the adjacent interdigital transducers of the other surface acoustic wave filter, a dummy electrode connected to a bus bar which faces a bus bar connected to the withdrawal-weighted electrode finger being disposed in the withdrawal-weighted portion.

27. A surface acoustic wave apparatus according to any one of claims 1 to 26, wherein said at least one surface acoustic wave filter is provided such that it possesses a balanced-signal-input and balanced-signal-output filtering function.

28. A surface acoustic wave apparatus according to any one of claims 1 to 26, wherein said at least one surface acoustic wave filter is provided such that it possesses a balanced-signal-input and unbalanced-signal-output filtering function or an unbalanced-signal-input and balanced-signal-output filtering function.

29. A surface acoustic wave apparatus according to claim 27,
wherein at least one of the interdigital transducers is divided into two portions in the direction of an interdigital length of the interdigital transducer.

30. A surface acoustic wave apparatus according to claim 27 or 29, wherein a pair of the balanced signal terminals are respectively connected to comb-like electrodes of one of the interdigital transducers.

31. A surface acoustic wave apparatus according to claim 27, wherein at least one of the interdigital transducers is divided into two portions in the direction in which the surface acoustic wave propagates.

32. A surface acoustic wave apparatus according to claim 27, wherein a grounded electrical neutral point is not provided between a pair of the balanced signal terminals.

33. A surface acoustic wave apparatus according to claim 1 or 2, wherein two of said surface acoustic wave filters are provided such that they possess a balanced-signal-input and balanced-signal output filtering function.

34. A surface acoustic wave apparatus according to claim 1 or 2, wherein two (1104,1105) of said surface acoustic wave filters are provided such that an output signal of one of the surface acoustic wave filters is about 180° out of phase with an output signal of the other surface acoustic wave filter, and the

surface acoustic wave filters are provided such that they possess a balanced-signal-input and unbalanced-signal-output filtering function or an unbalanced-signal-input and balanced-signal-output filtering function.

35. A surface acoustic wave apparatus according to claim 34, further comprising a surface acoustic wave filter (1201) being cascade-connected to an unbalanced signal terminal.

36. A surface acoustic wave apparatus according to claim 1 or 2, wherein said at least one surface acoustic wave filter is a longitudinal-coupling-resonator-type surface acoustic wave filter.

37. A surface acoustic wave apparatus according to claim 36, wherein said longitudinal-coupling-resonator-type surface acoustic wave filter comprises an odd number of the interdigital transducers (1-3).

38. A surface acoustic wave apparatus according to claim 37, wherein said longitudinal-coupling-resonator-type surface acoustic wave filter comprises three interdigital transducers (1-3).

39. A surface acoustic wave apparatus according to claim 36, wherein the total number of electrode fingers of at least one of the interdigital transducers of said longitudinal-coupling-resonator-type surface acoustic wave filter is an even number.

40. A surface acoustic wave apparatus according to claim 39, wherein at least three of the interdigital transducers (1-3) are provided, and the total number of the electrode fingers of at least the interdigital transducer connected to a balanced signal terminal (6/7) is an even number.

41. A surface acoustic wave apparatus according to claim 39, wherein at least three of the interdigital transducers (1-3) are provided, and the total number of the electrode fingers of at least the interdigital transducer (1) located at the center of at least three of the interdigital transducers is an even number.

42. A surface acoustic wave apparatus according to claim 1 or 2, wherein at least one surface acoustic wave resonator is connected in series to or in parallel with said at least one surface acoustic wave filter.

43. A surface acoustic wave apparatus according to claim 1 or 2, wherein said at least one surface acoustic wave filter is formed by cascade-connecting at least two surface acoustic wave filter portions.

44. A surface acoustic wave apparatus comprising:

an input interdigital transducer (1/2,3) including a plurality of electrode fingers; and
an output interdigital transducer (2/3) including a plurality of electrode fingers, said input interdigital transducer and said output interdigital transducer being disposed on a piezoelectric substrate (8) in a direction in which a surface acoustic wave propagates so as to form a longitudinal-coupling-resonator-type,

wherein weighting is applied to an inner electrode finger other than an outermost electrode finger of at least one (1/2/3) of said input interdigital transducer and said output interdigital transducer.

45. A surface acoustic wave apparatus according to claim 44, wherein one of said input interdigital transducer and said output interdigital transducer is connected to a balanced side, and the input interdigital transducer or the output interdigital transducer connected to the balanced side includes the weighted electrode finger.

46. A surface acoustic wave apparatus according to claim 44, wherein the weighted electrode finger is located within one half a total width of all the electrode fingers of the corresponding interdigital transducer from the outermost electrode finger of the interdigital transducer.

47. A surface acoustic wave apparatus according to claim 44, wherein at least two ground electrode fingers including the outermost electrode finger of at least one of the input interdigital transducer and the output interdigital transducer are sequentially provided, the outermost electrode finger being located such that it faces the other interdigital transducer.

48. A surface acoustic wave apparatus according to claim 44, wherein the weighted electrode finger is set such that it controls an area of a no-electric-field portion formed between adjacent ground electrode fingers of at least one of the input interdigital transducer and the output interdigital transducer.

49. A surface acoustic wave apparatus according to claim 48, wherein one of the input interdigital transducer and the output interdigital transducer is connected to a balanced side, and an area of the no-electric-field portion of one of the two balanced interdigital transducers is substantially equal to an area of the non-electric-field portion of the other balanced interdigital transducer.

50. A surface acoustic wave apparatus according to claim 44, wherein the weighted electrode finger is

set to be shorter than the other electrode fingers.

51. A surface acoustic wave apparatus according to claim 44, wherein a first grounded balance electrode finger is formed to extend toward the weighted electrode finger such that a length of the first grounded balance electrode finger becomes equal to a length of the weighted electrode finger.

52. A surface acoustic wave apparatus according to claim 44, wherein a second grounded balance electrode finger (21b) is formed to extend in a direction different from the direction of the weighted electrode finger (22a) such that a length of the second grounded balance electrode finger becomes equal to a length of the weighted electrode finger, and a bending dummy electrode (25a) is provided such that it faces the second grounded balance electrode finger and the weighted electrode finger.

53. A surface acoustic wave apparatus according to claim 44, wherein said surface acoustic wave apparatus is provided with an unbalanced-to-balanced conversion function.

54. A communications unit using the surface acoustic wave apparatus set forth in any previous claim.

FIG. 1

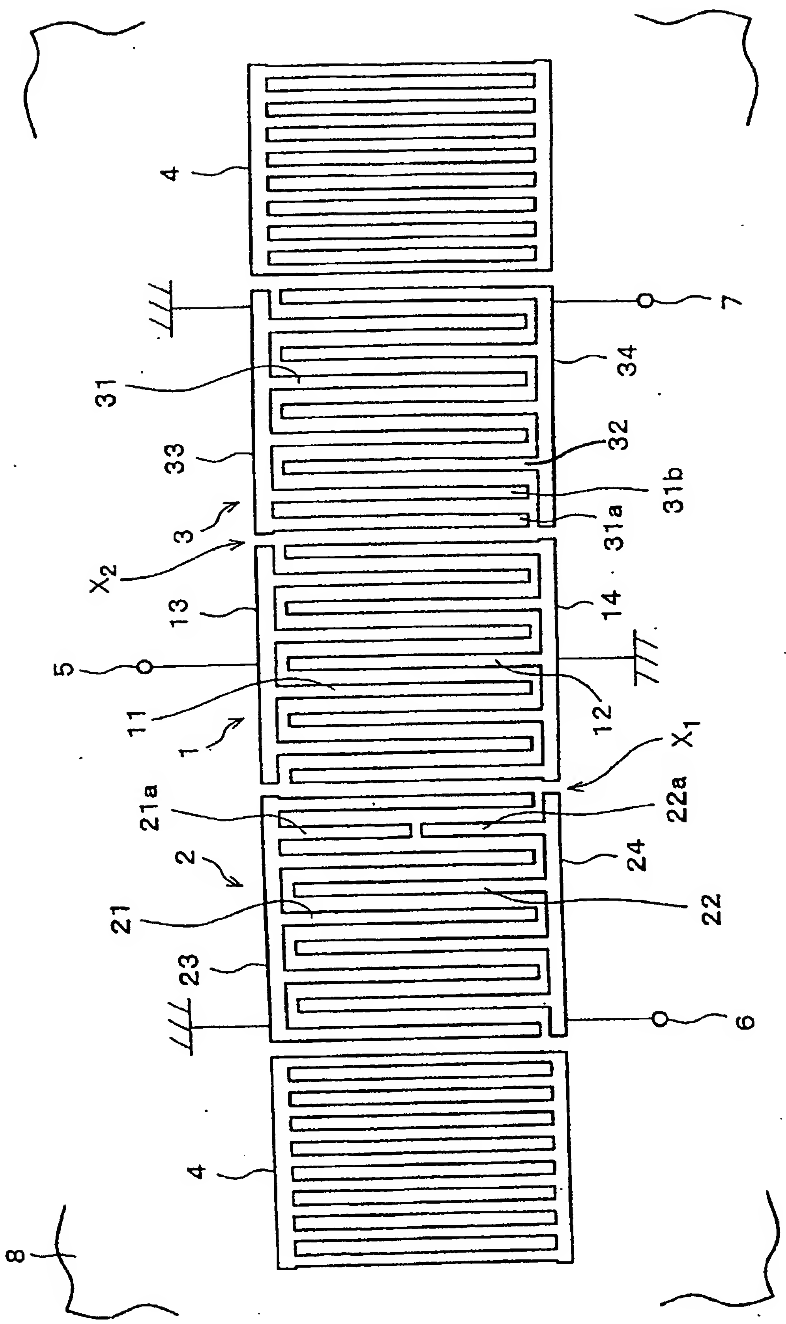


FIG. 2

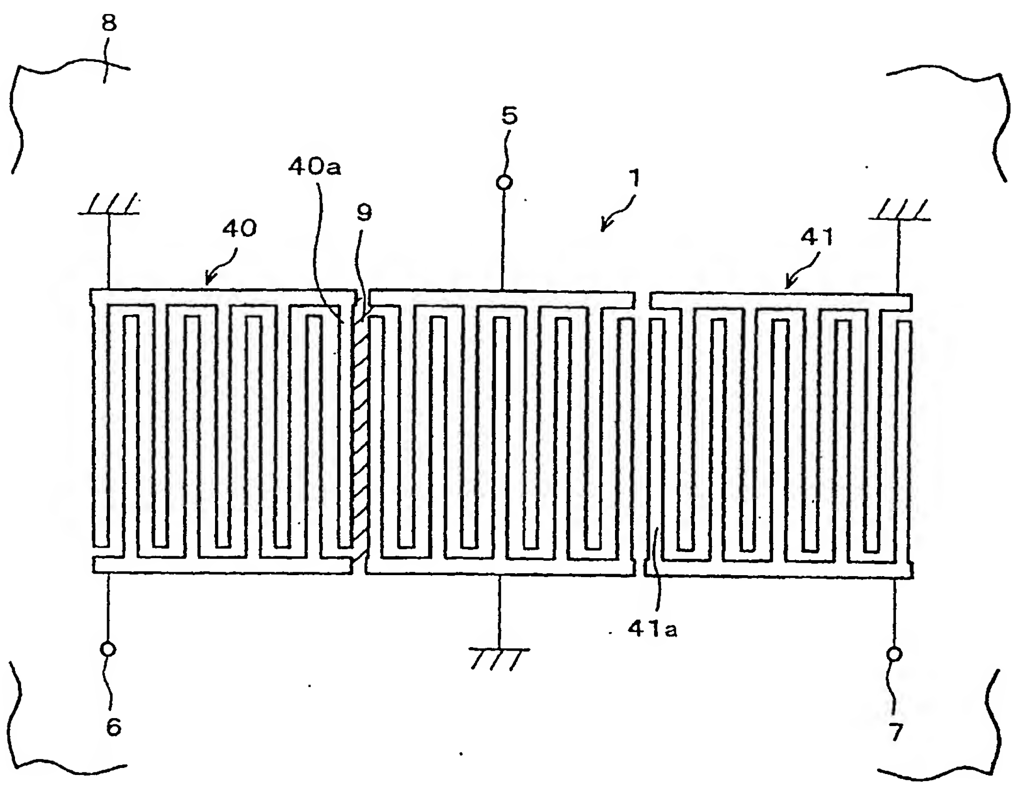


FIG. 3

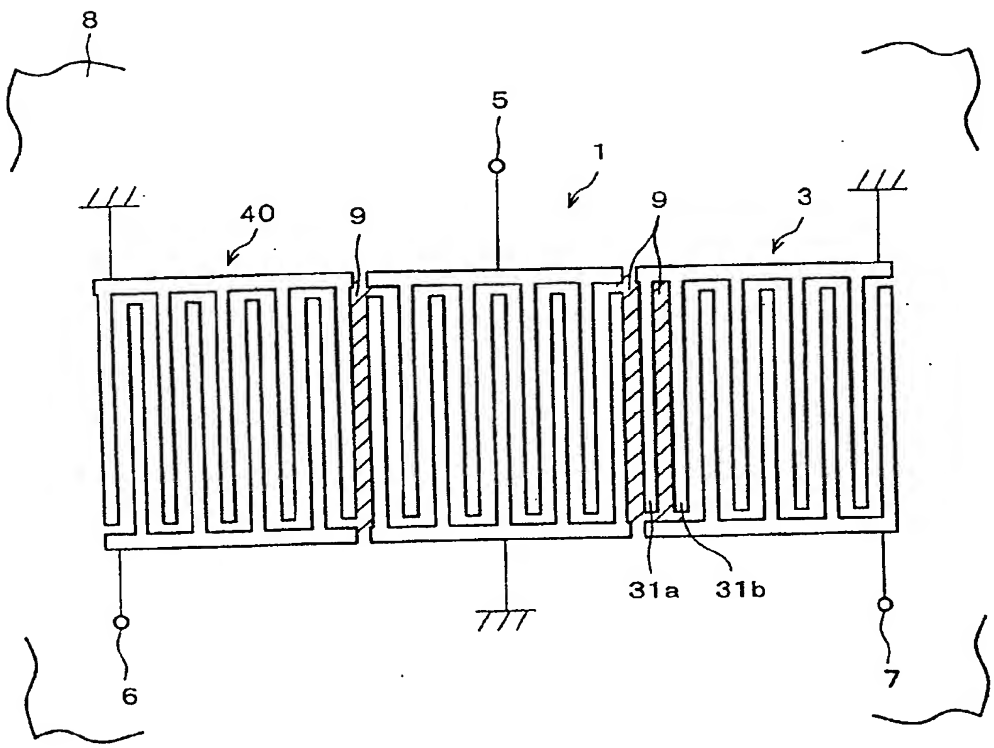


FIG. 4

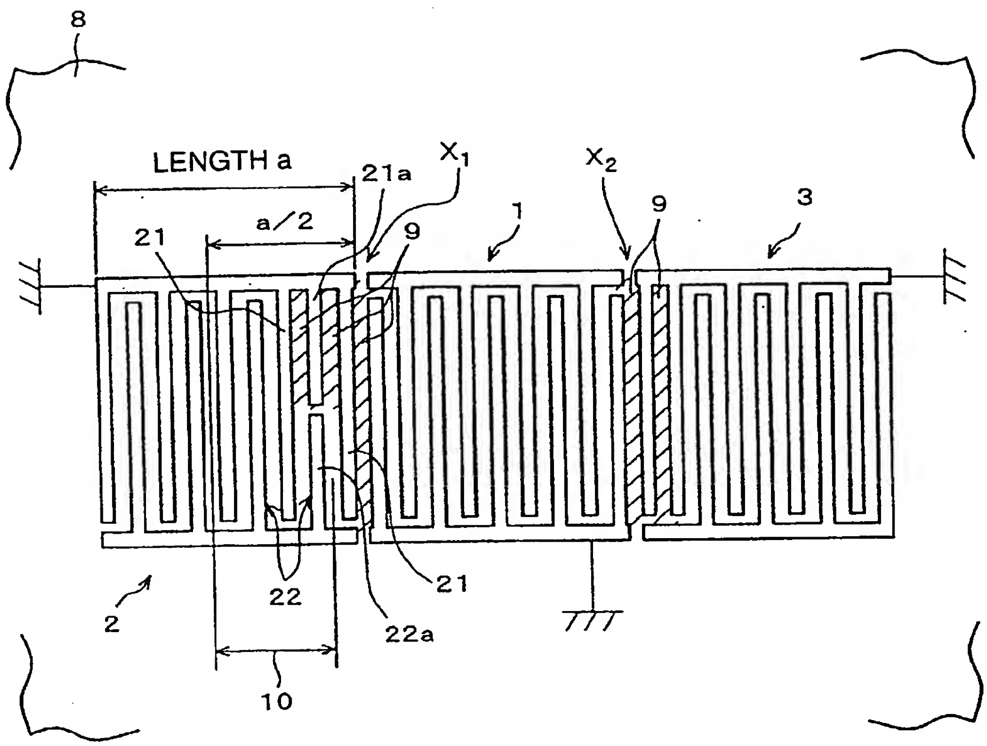


FIG. 5

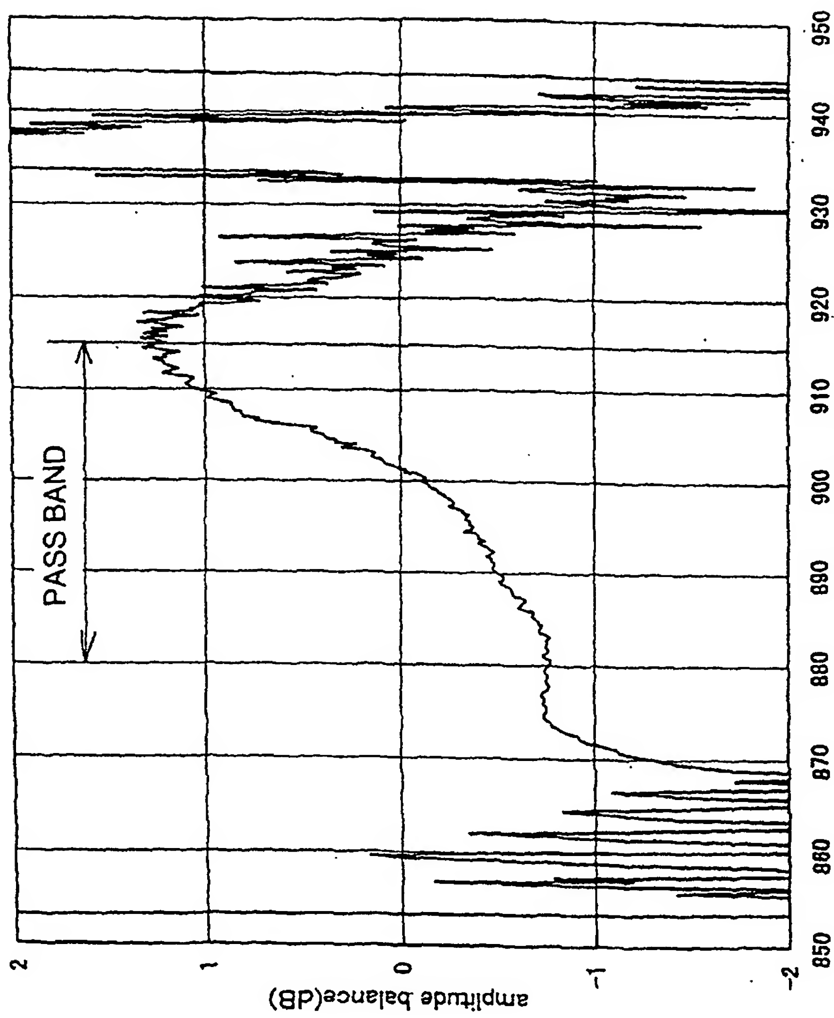
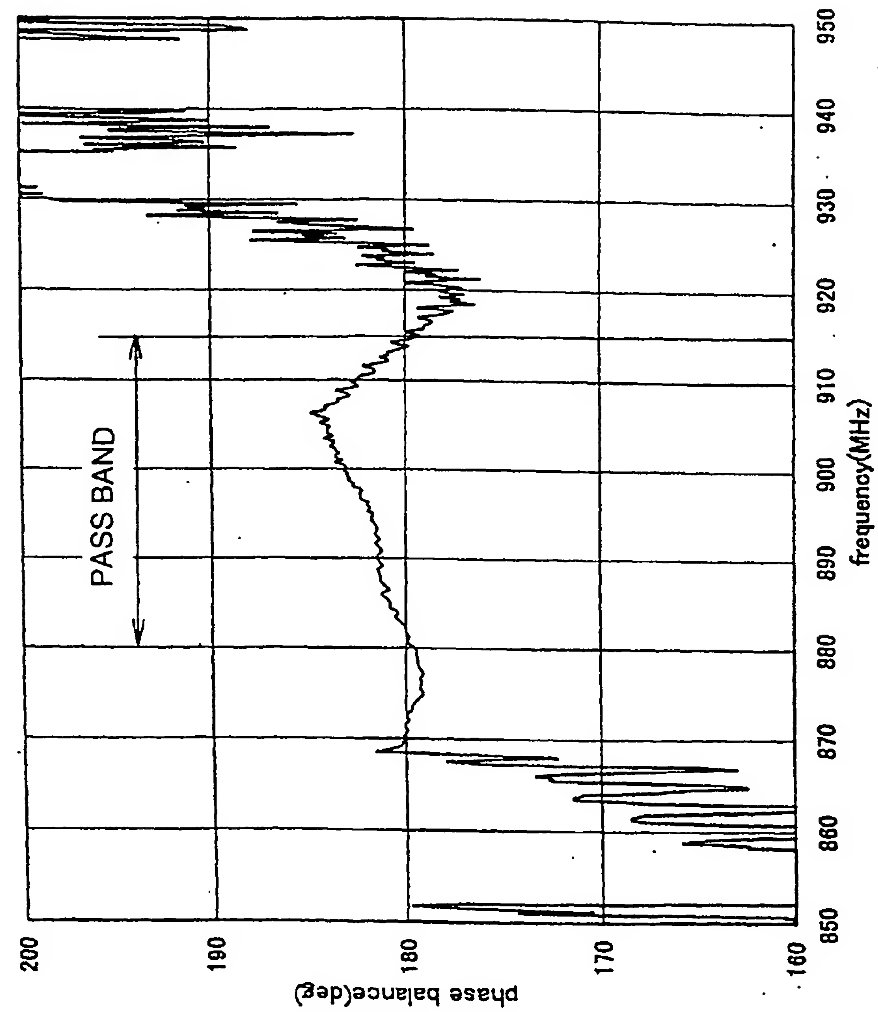

PASS BAND
amplitude balance(dB)
2
1
0
-1
-2
850
860
870
880
890
900
910
920
930
940
950

FIG. 6


PASS BAND
phase balance(deg)
200
190
180
170
160
frequency(MHz)
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860
870
880
890
900
910
920
930
940
950

FIG. 7

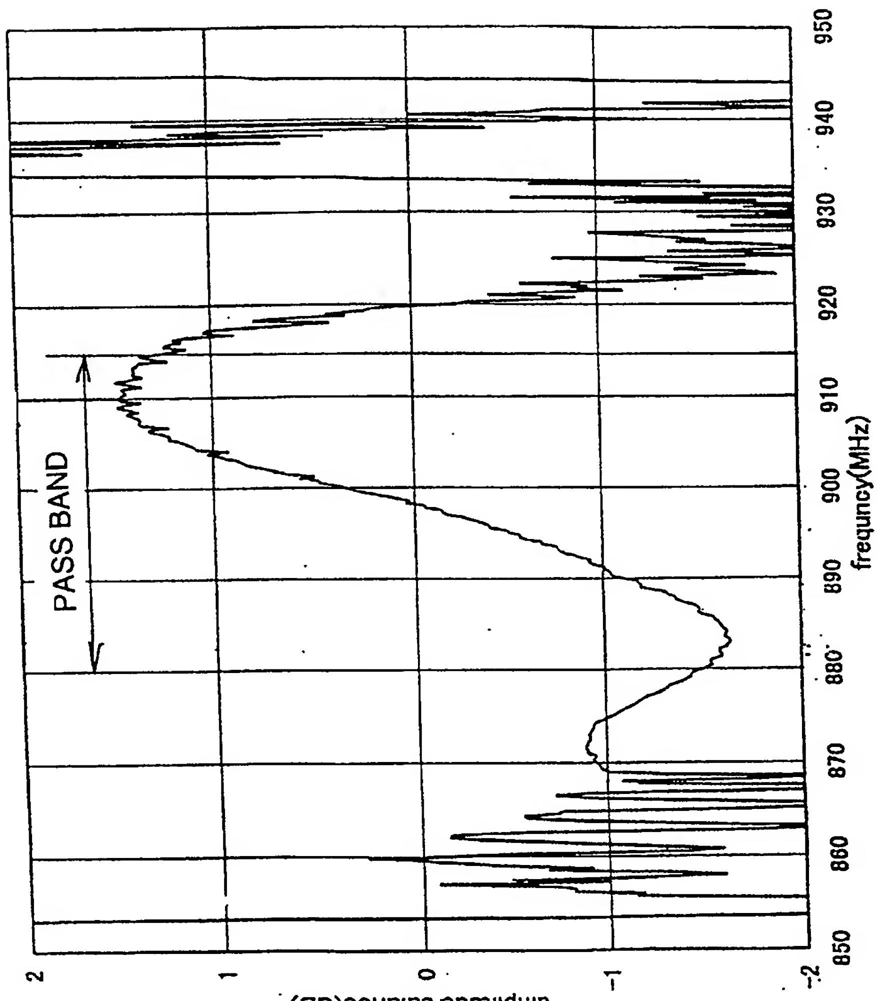
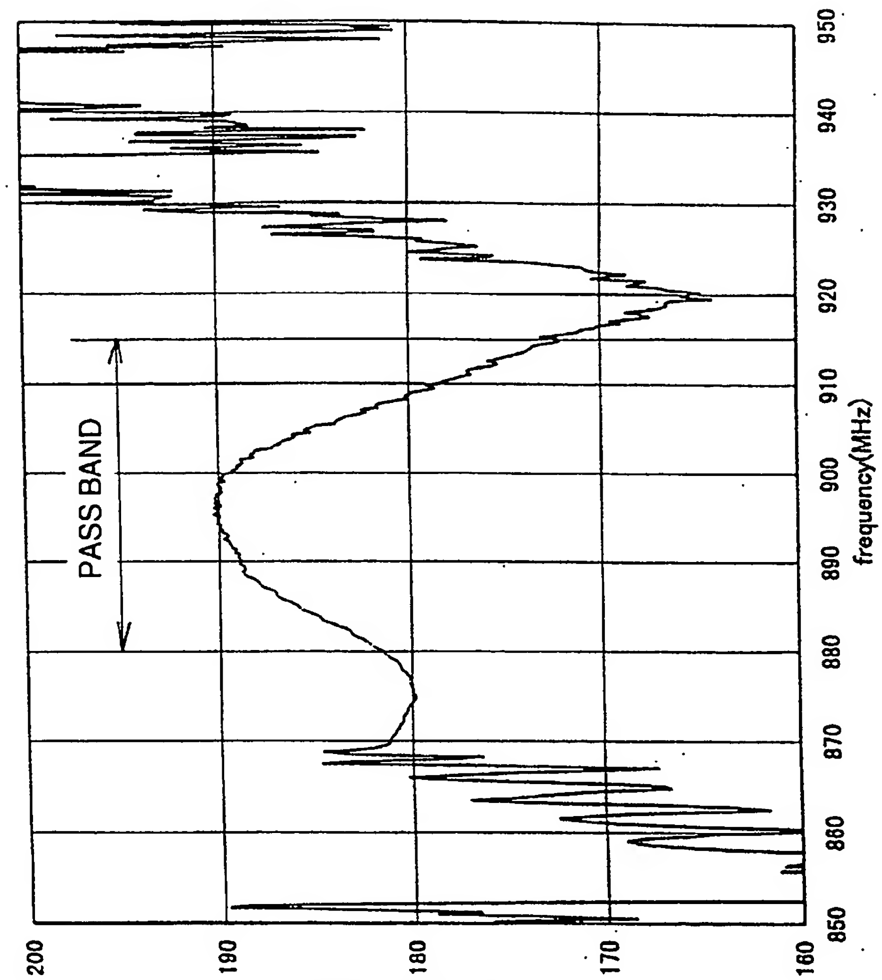

PASS BAND
amplitude balance(dB)
frequncy(MHz)
2
1
0
-1
-2
850
860
870
880
890
900
910
920
930
940
950

FIG. 8


PASS BAND
frequency(MHz)
phase balance(deg)
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860
870
880
890
900
910
920
930
940
950
200
190
180
170
160

FIG.9

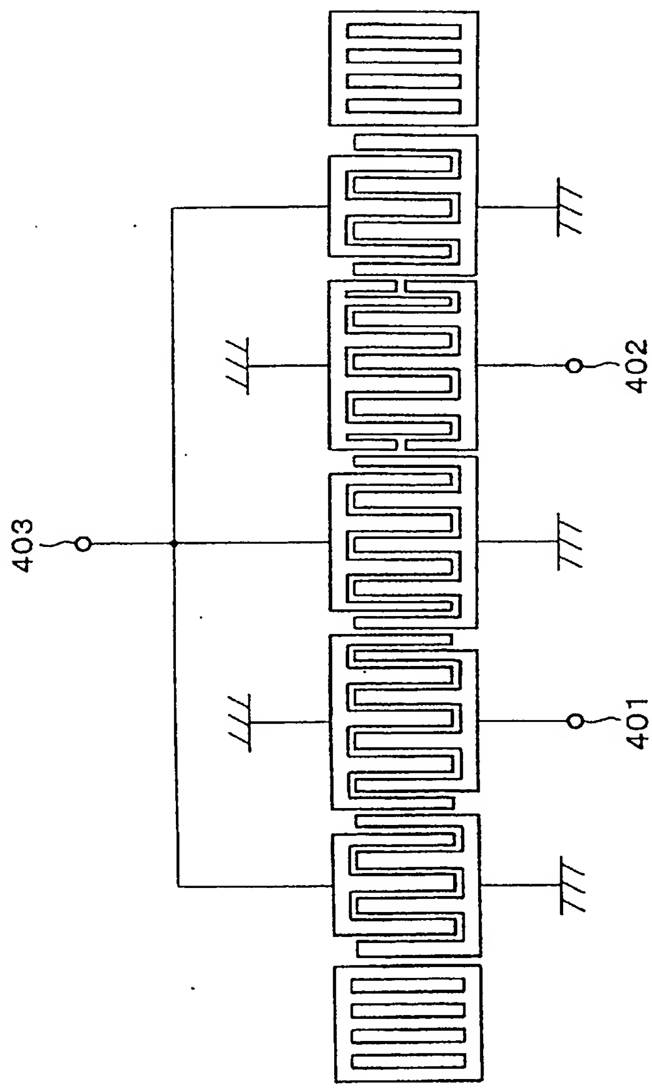


FIG. 10

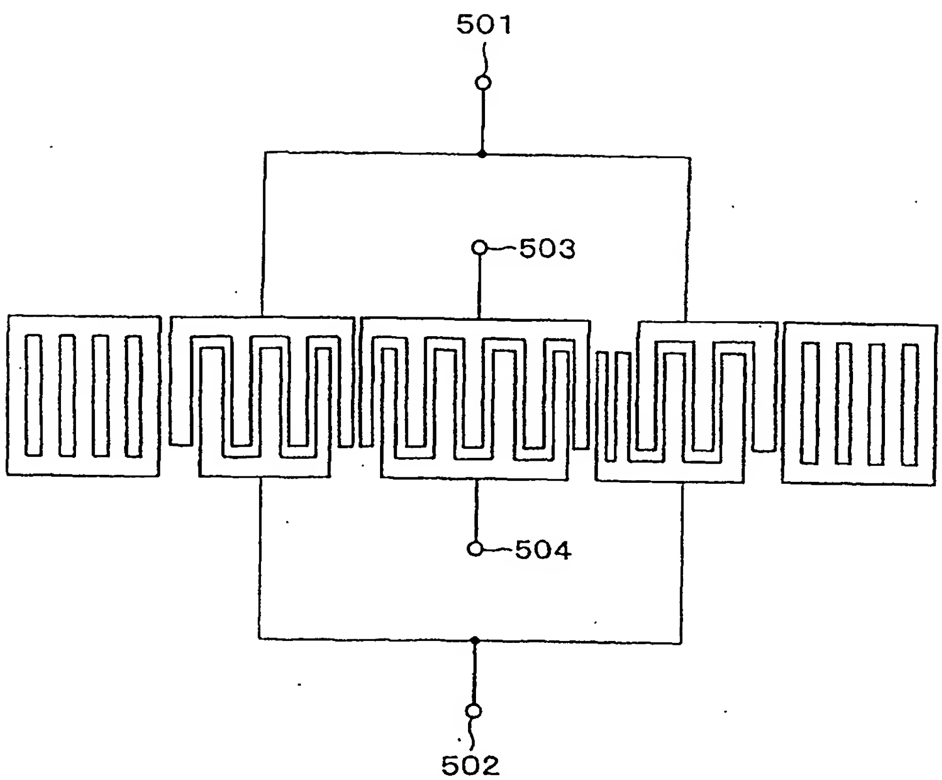


FIG. 11

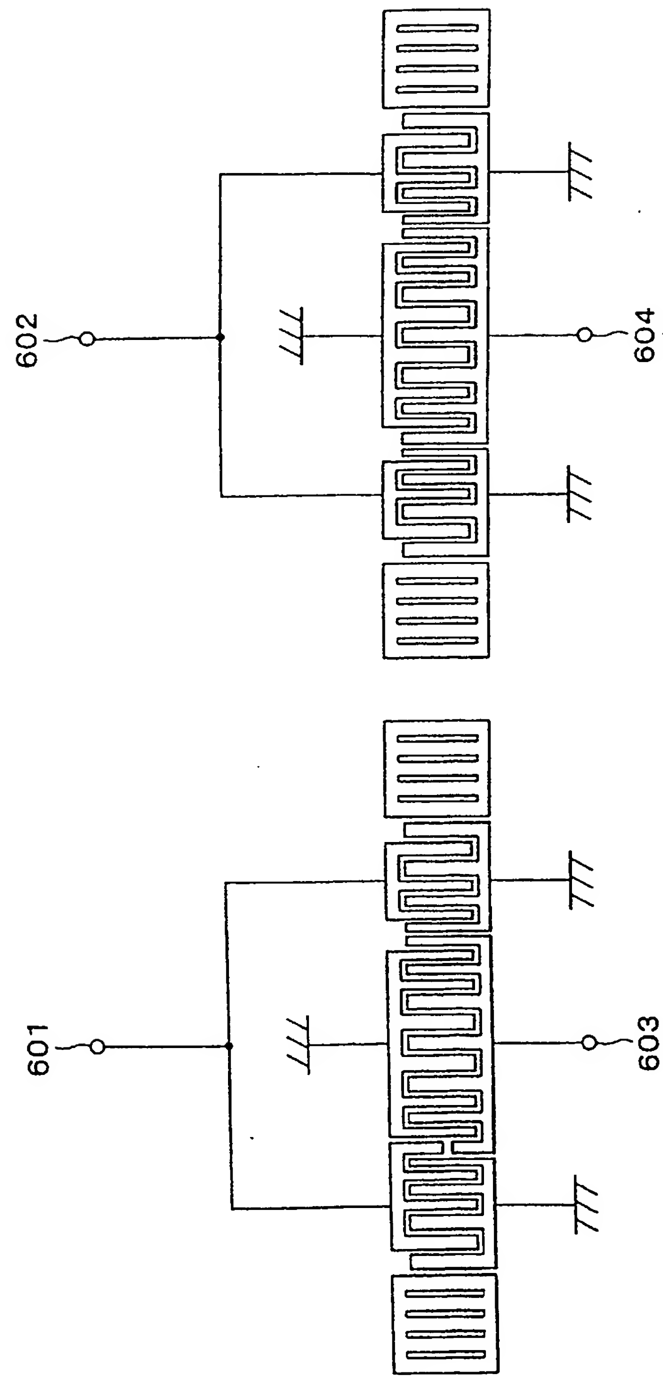


FIG. 12

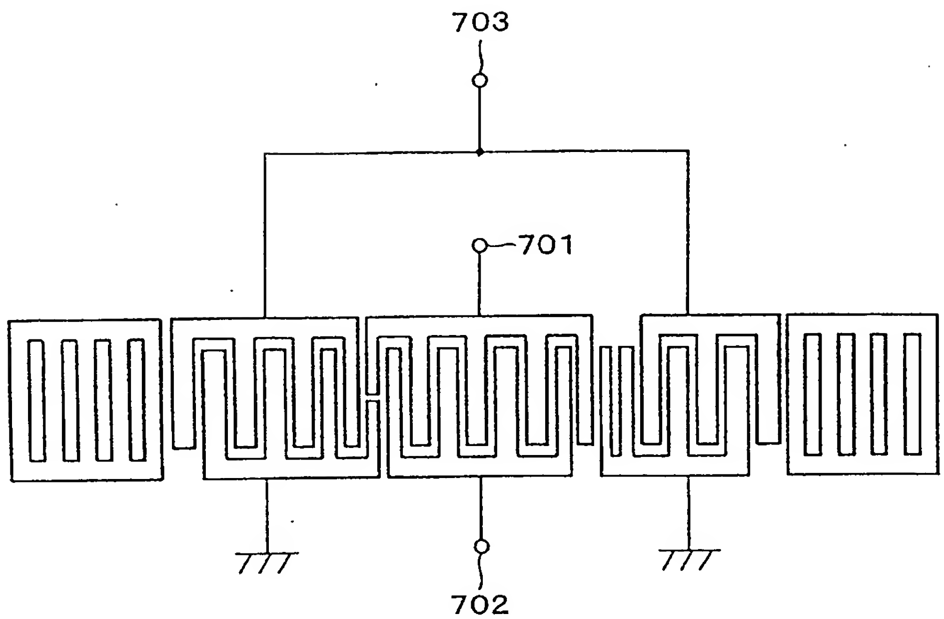


FIG. 13

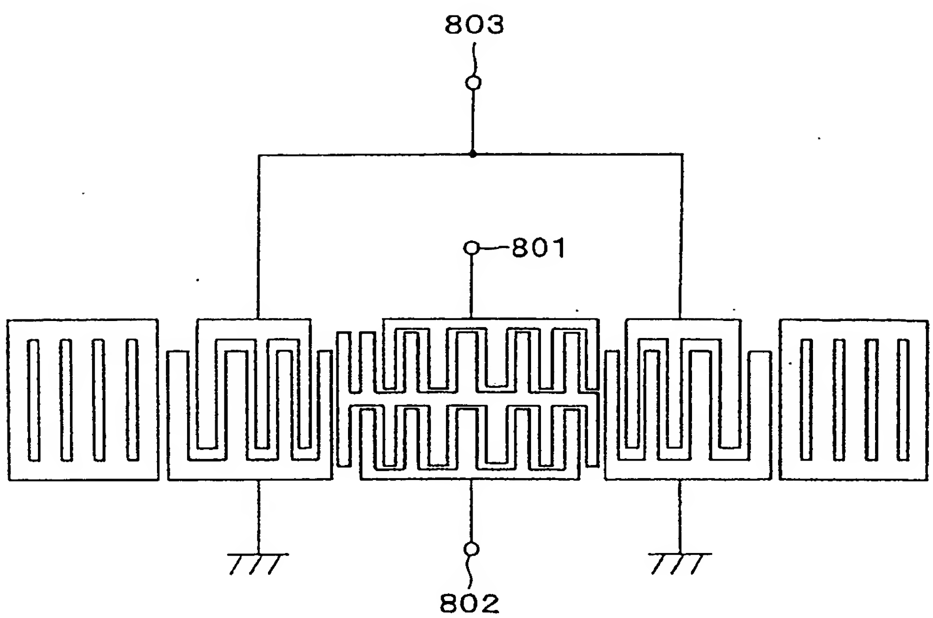


FIG. 14

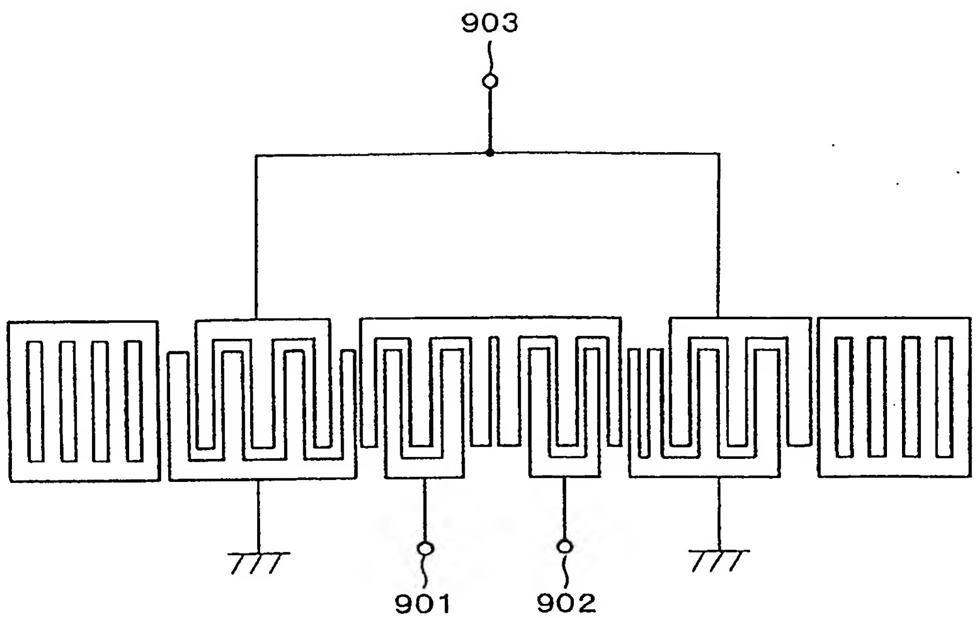


FIG. 15

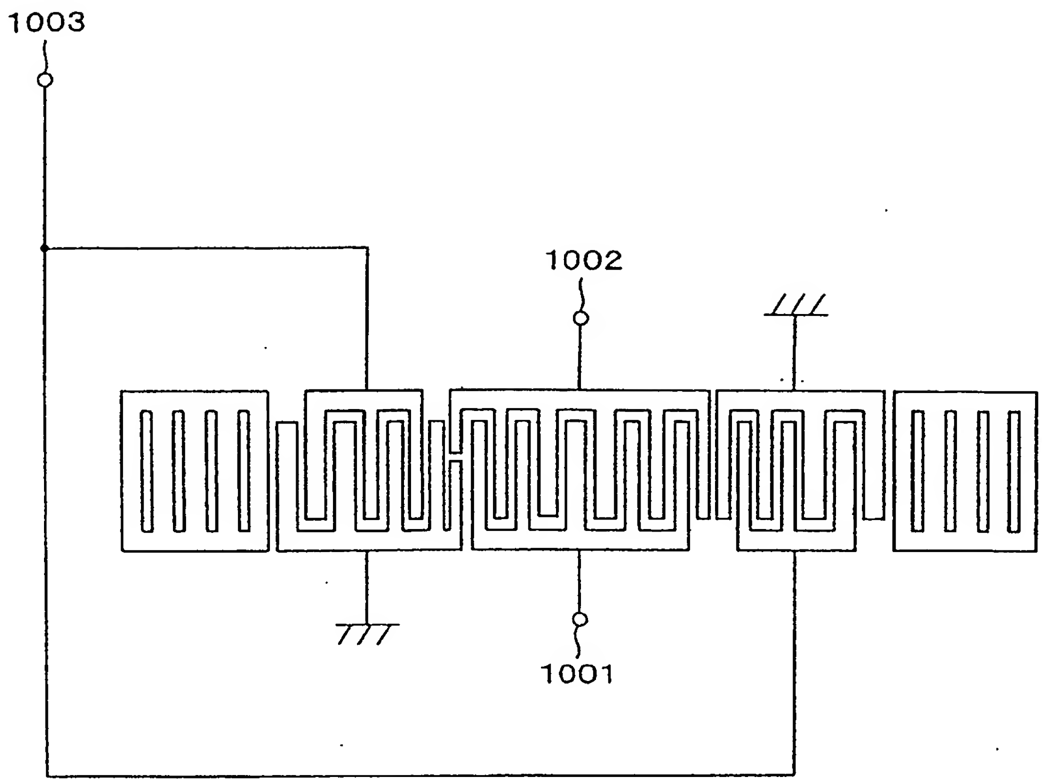


FIG. 16

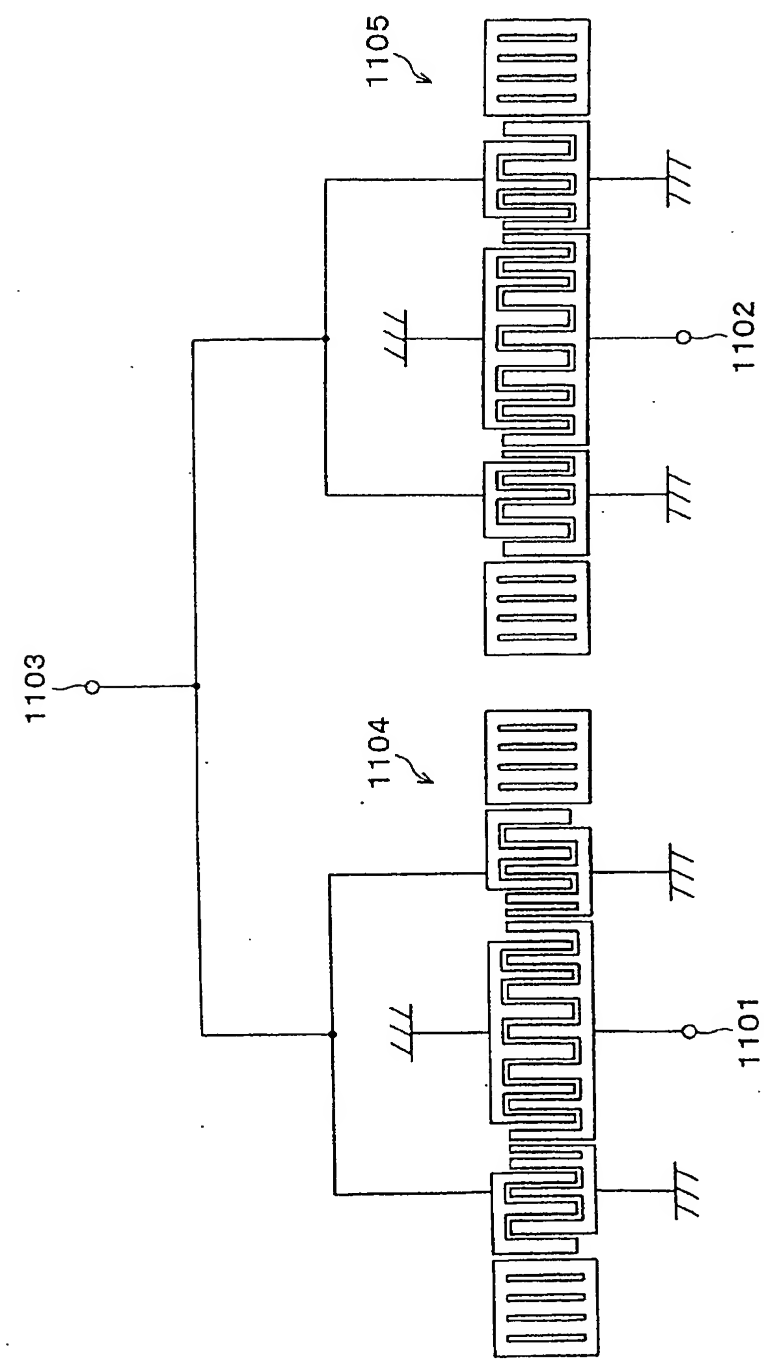


FIG. 17

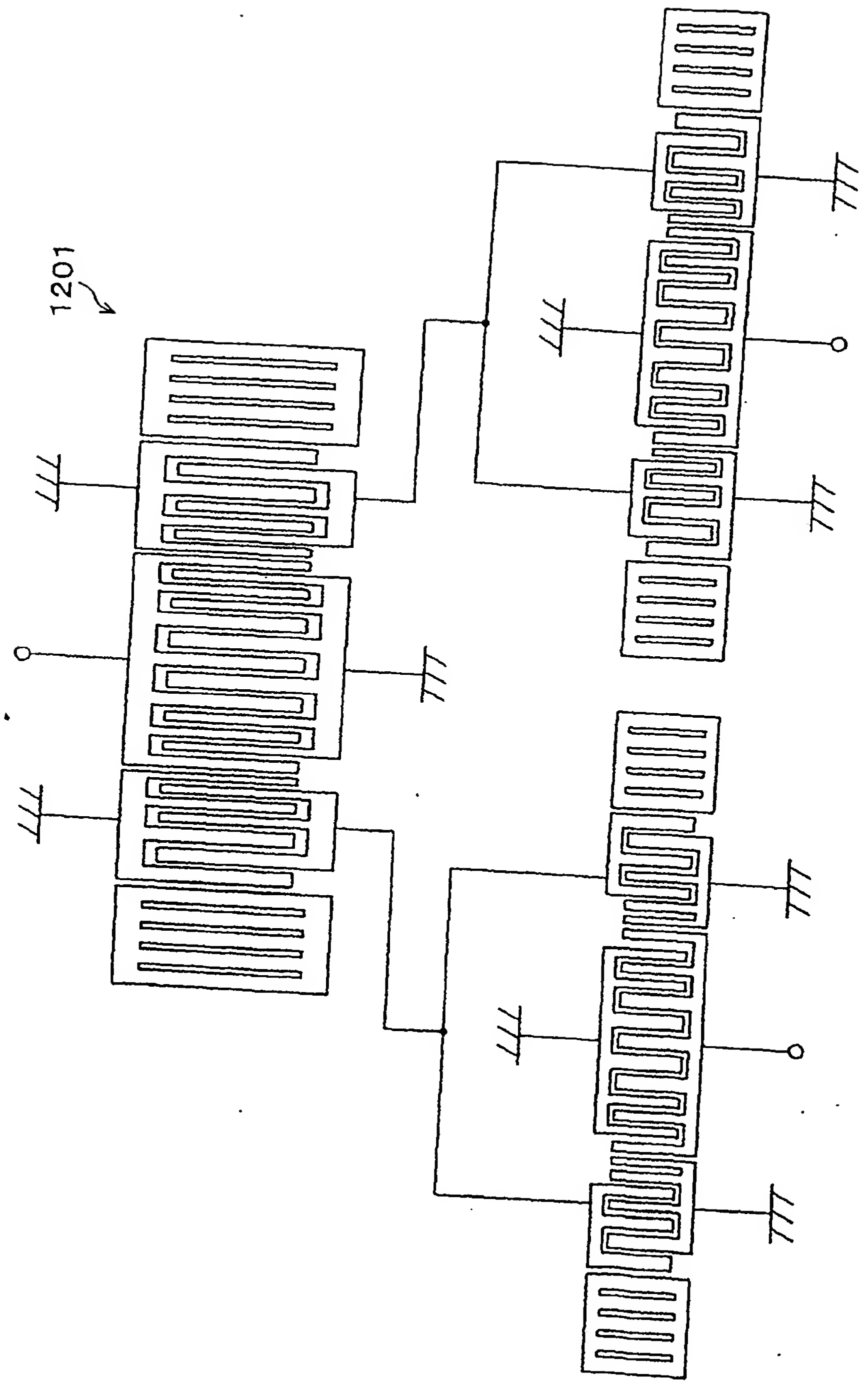


FIG. 18

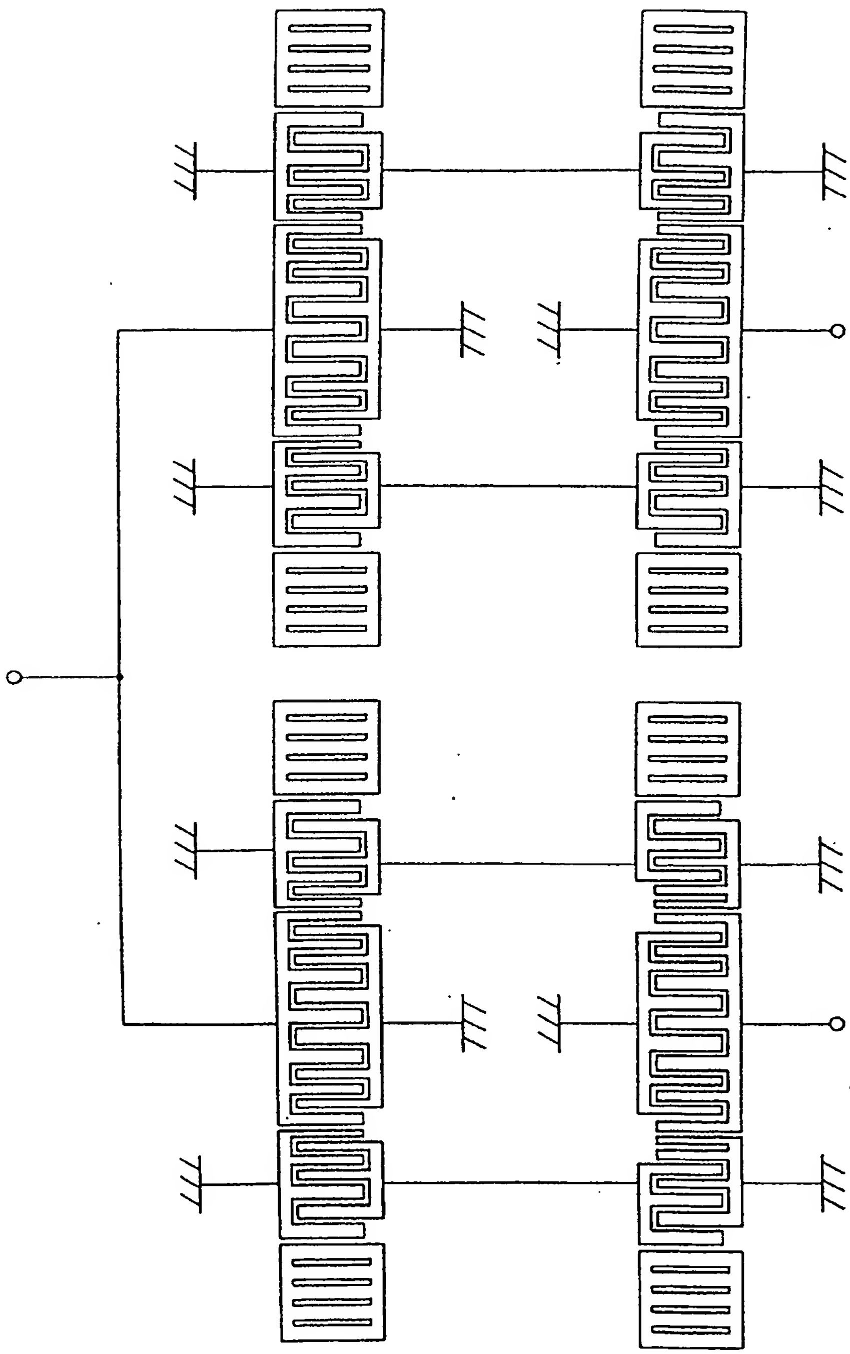


FIG. 19

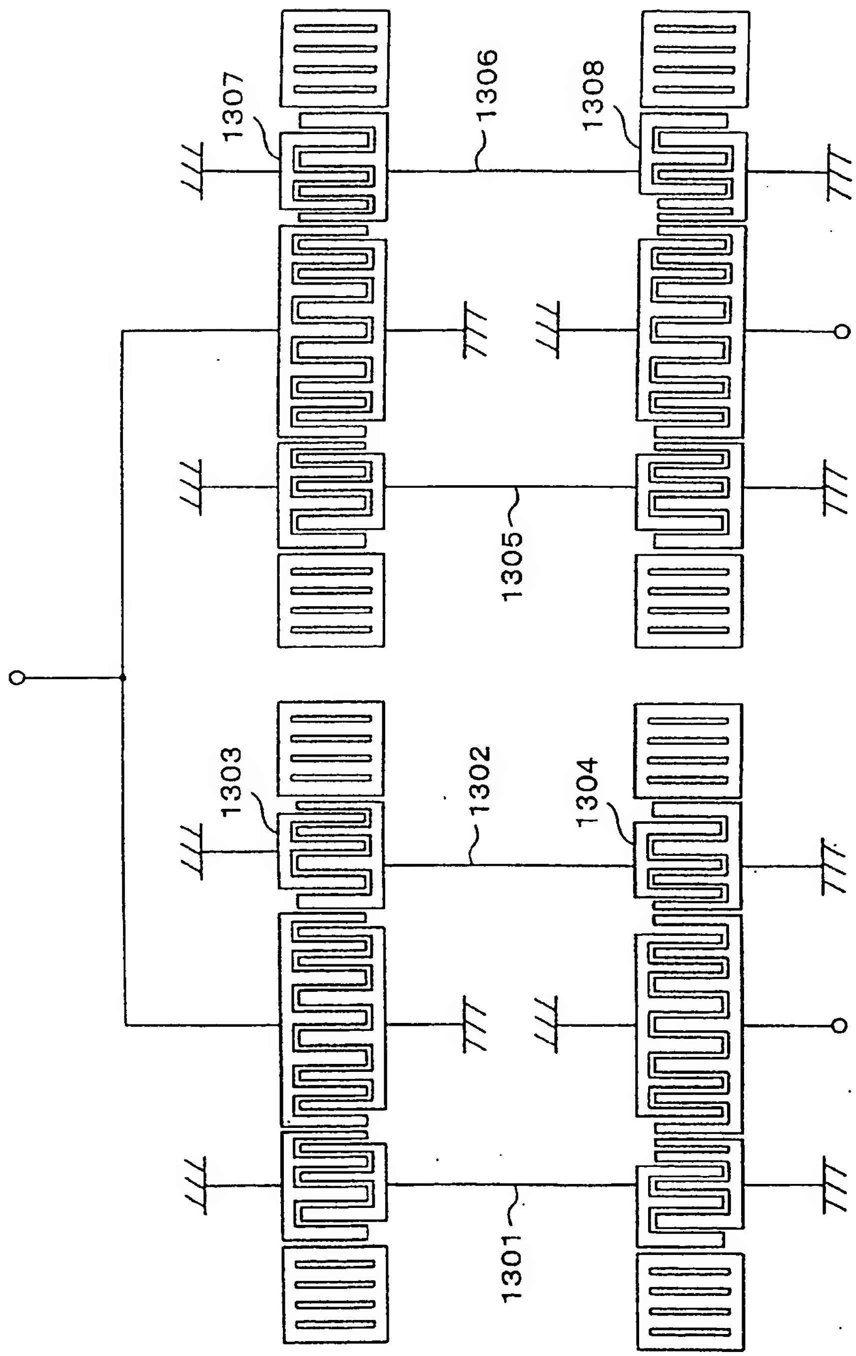


FIG. 20

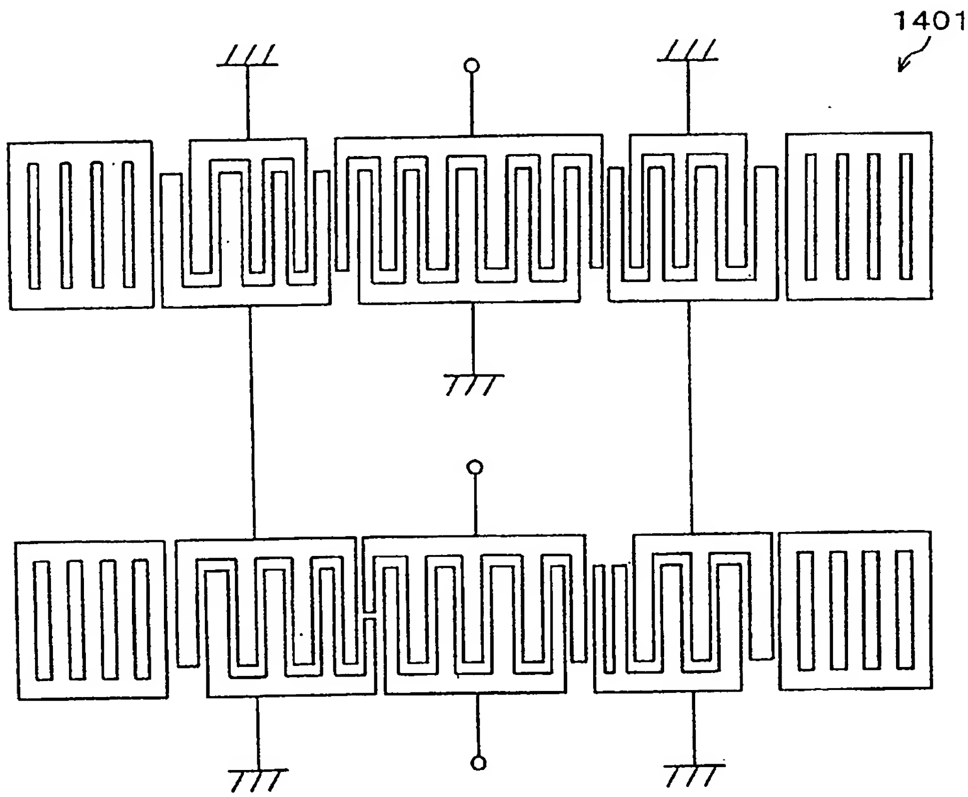


FIG. 21

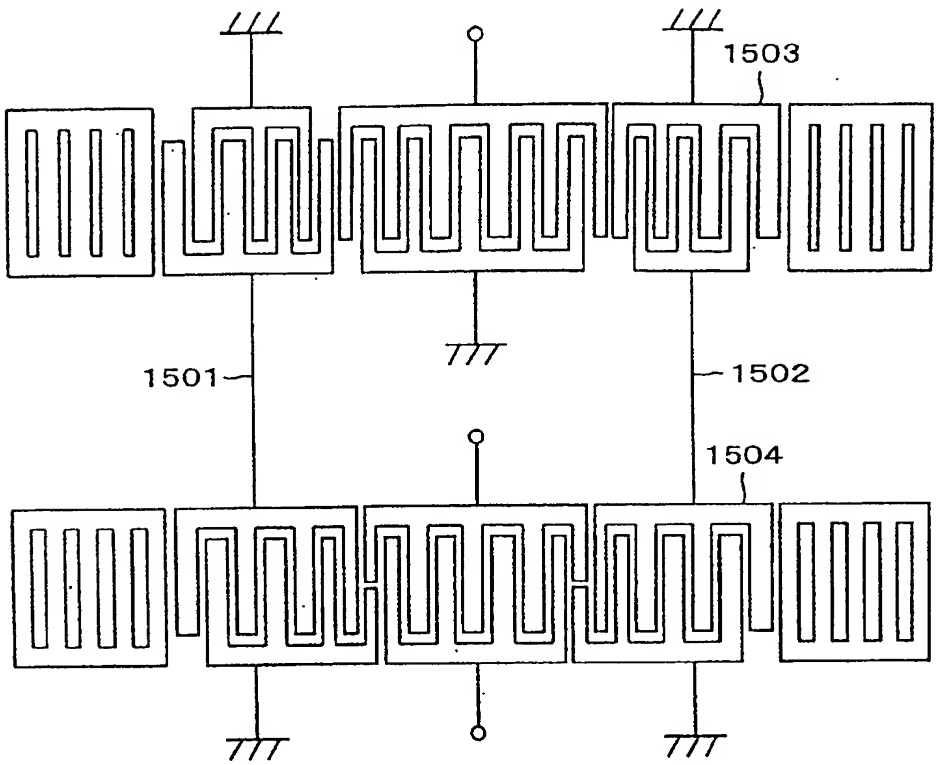


FIG. 22

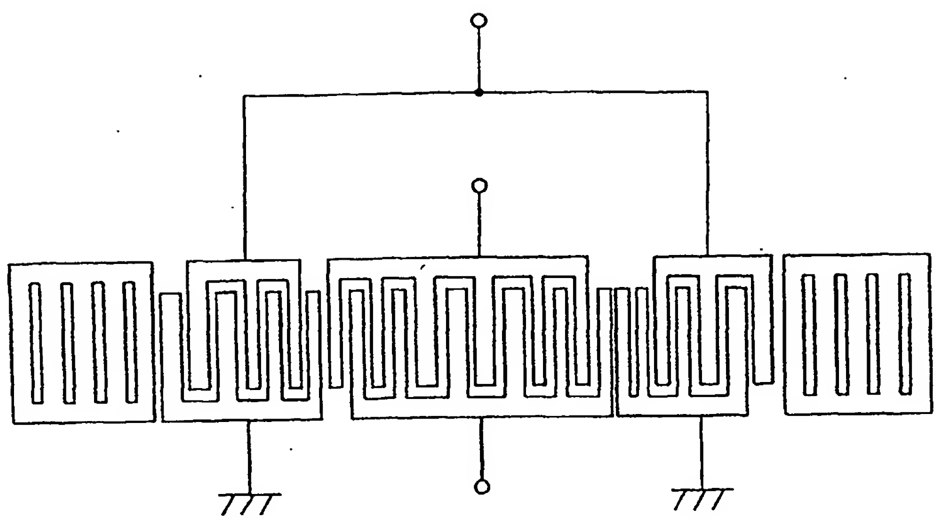


FIG. 23

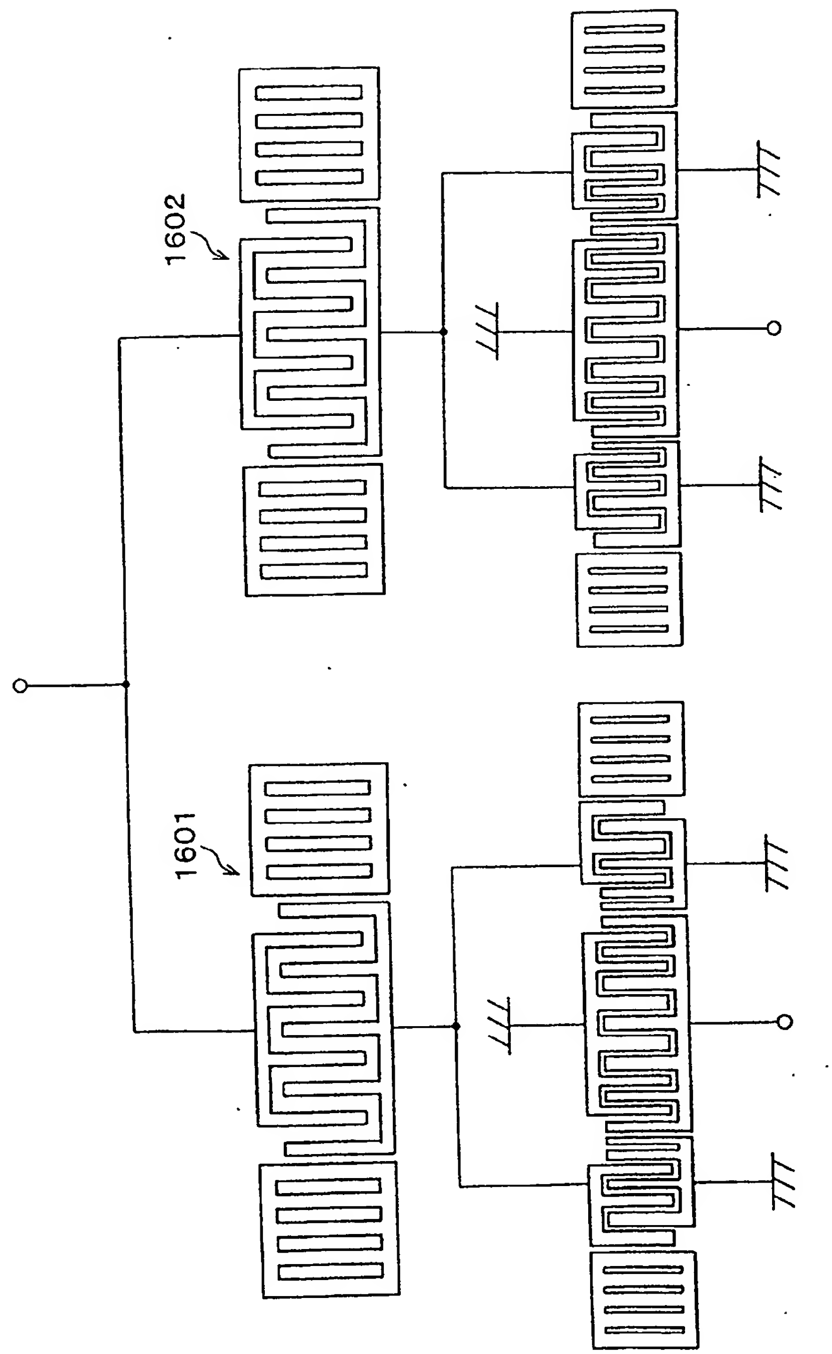


FIG. 24

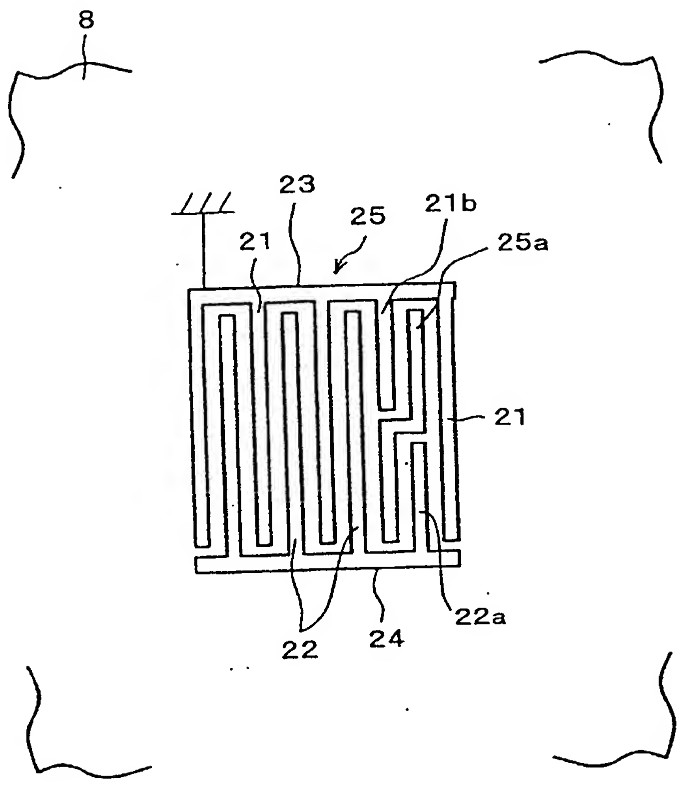


FIG. 25

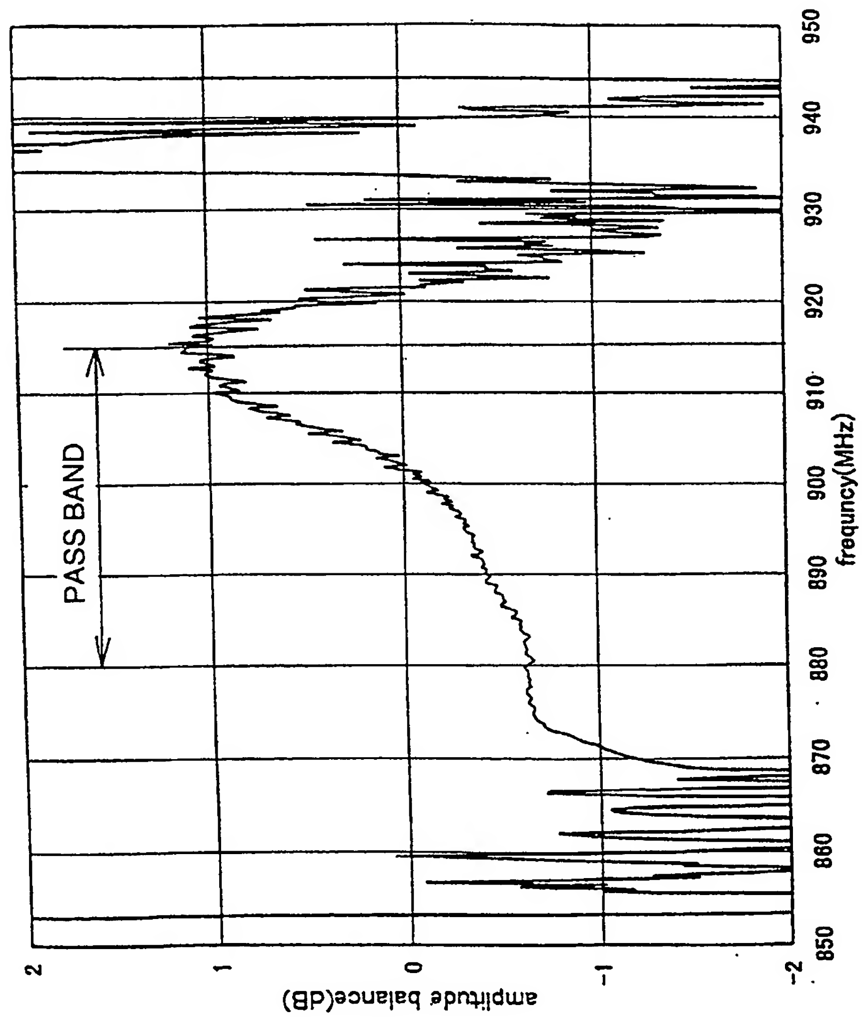

PASS BAND
frequncy(MHz)
850
860
870
880
890
900
910
920
930
940
950
amplitude balance(dB)
2
1
0
−1
−2

FIG. 26

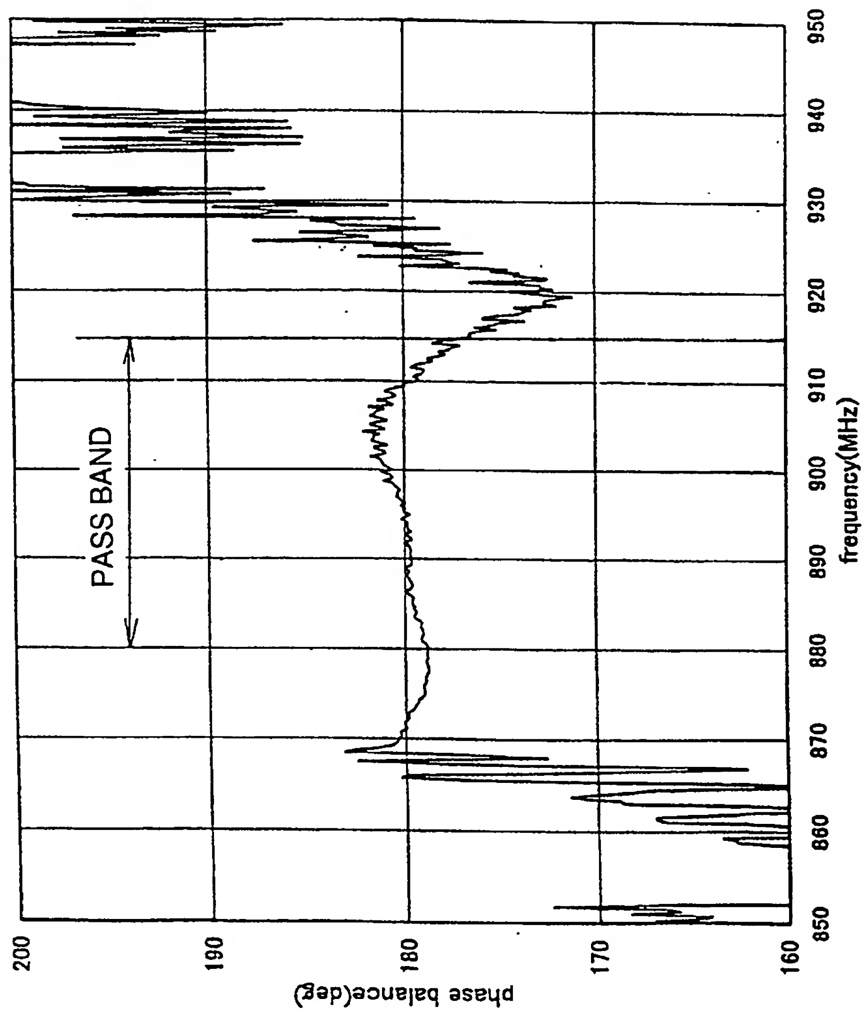

PASS BAND
phase balance(deg)
200
190
180
170
160
frequency(MHz)
850
860
870
880
890
900
910
920
930
940
950

FIG. 27

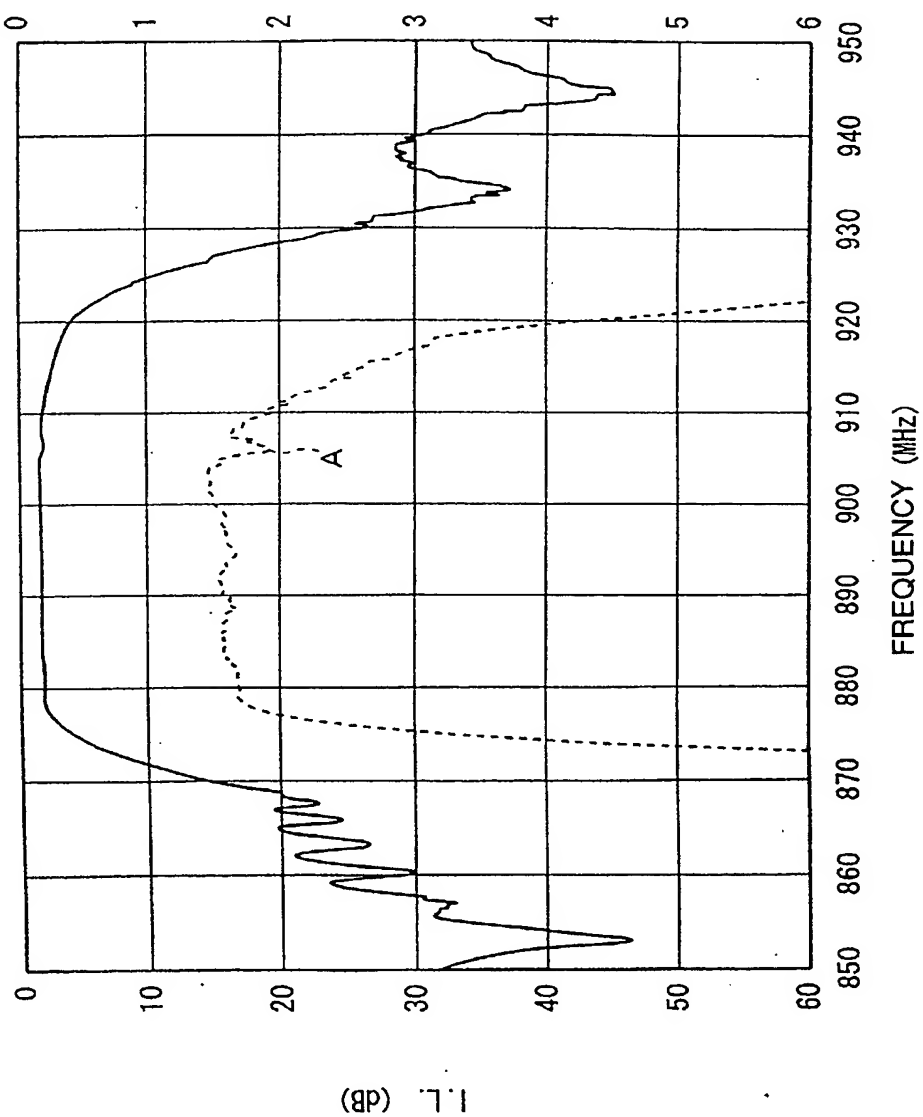

FREQUENCY (MHz)
I.L. (dB)
A
850 860 870 880 890 900 910 920 930 940 950
0 10 20 30 40 50 60
0 1 2 3 4 5 6

FIG. 28

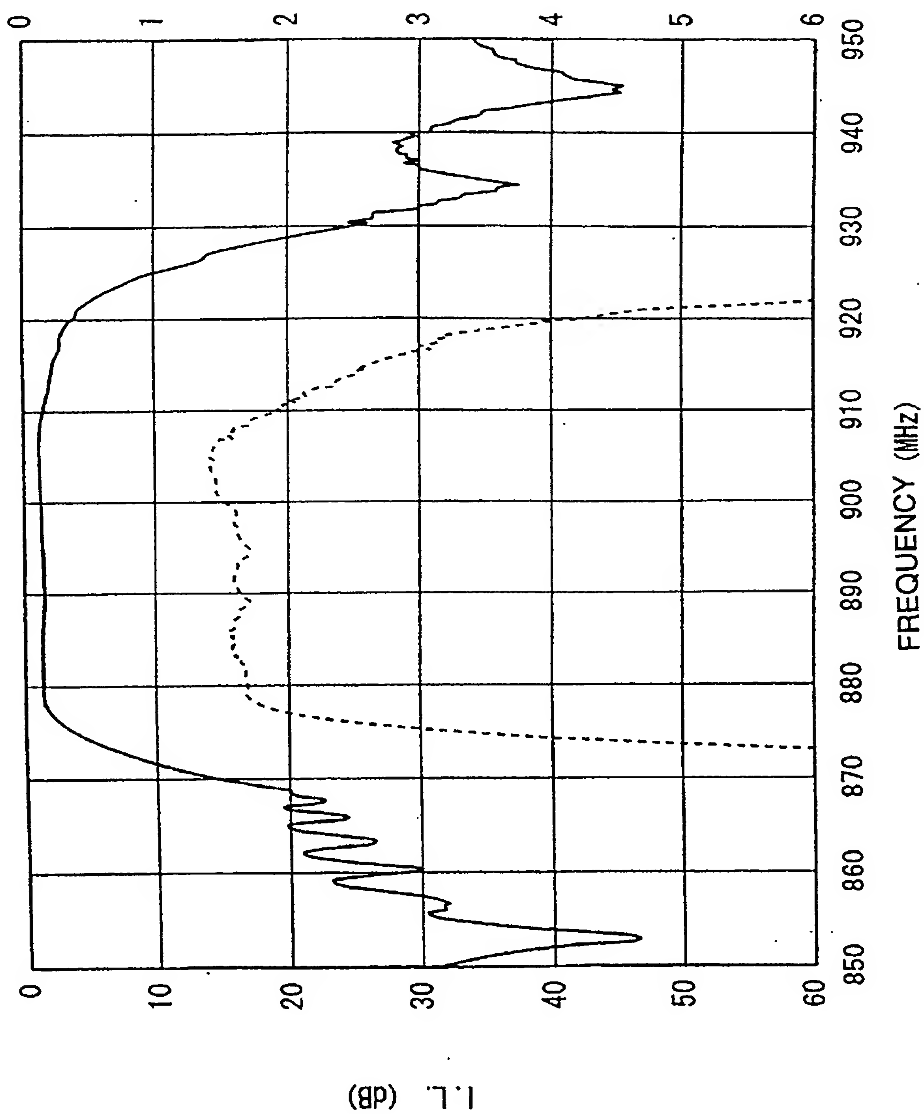

0
1
2
3
4
5
6
0
10
20
30
40
50
60
I.L. (dB)
850
860
870
880
890
900
910
920
930
940
950
FREQUENCY (MHz)

FIG. 29

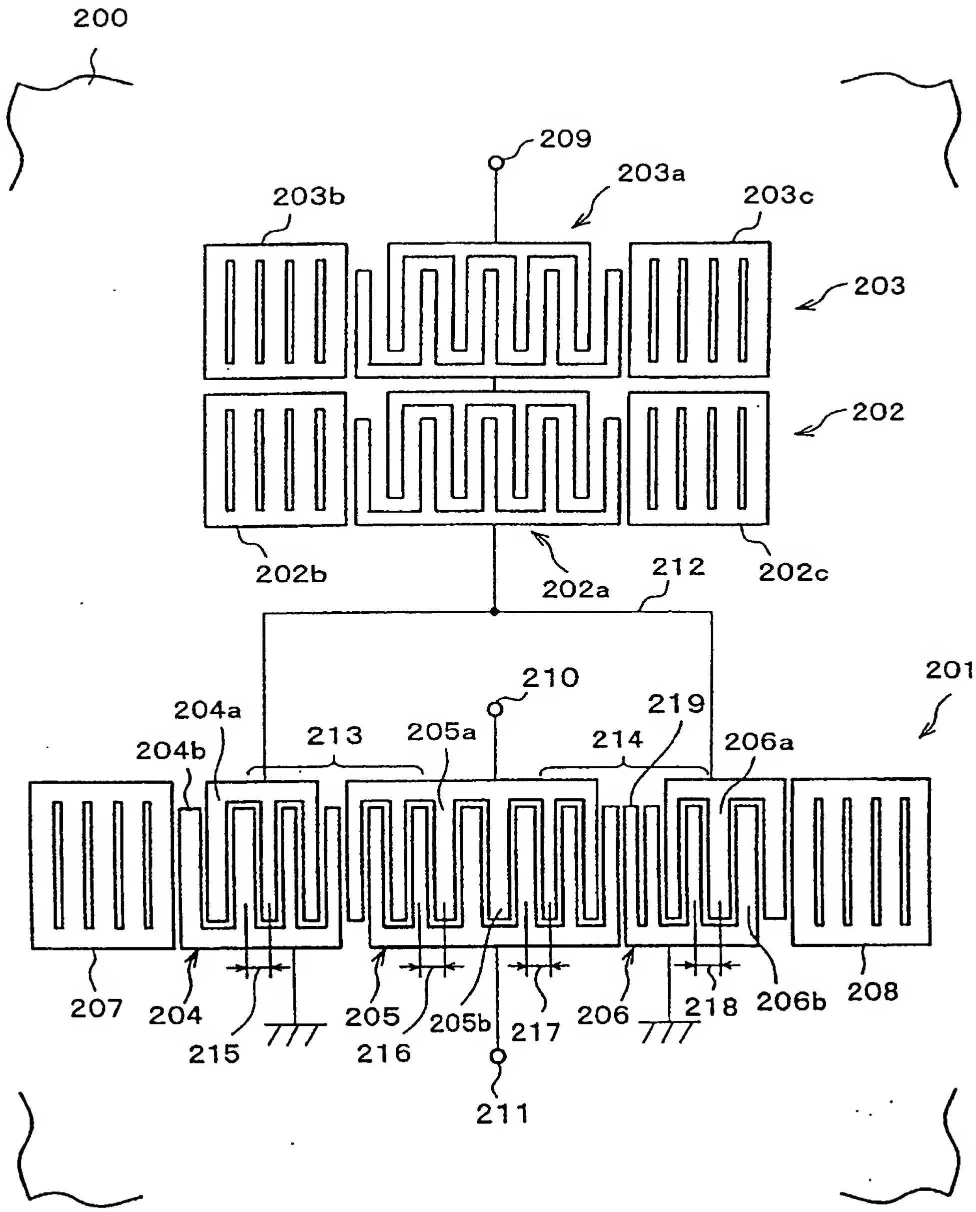

200
209
203a
203b
203c
203
202
202b
202a
212
202c
201
210
219
204a
213
205a
214
206a
204b
207
204
215
205
216
205b
217
206
218
206b
208
211

FIG. 30

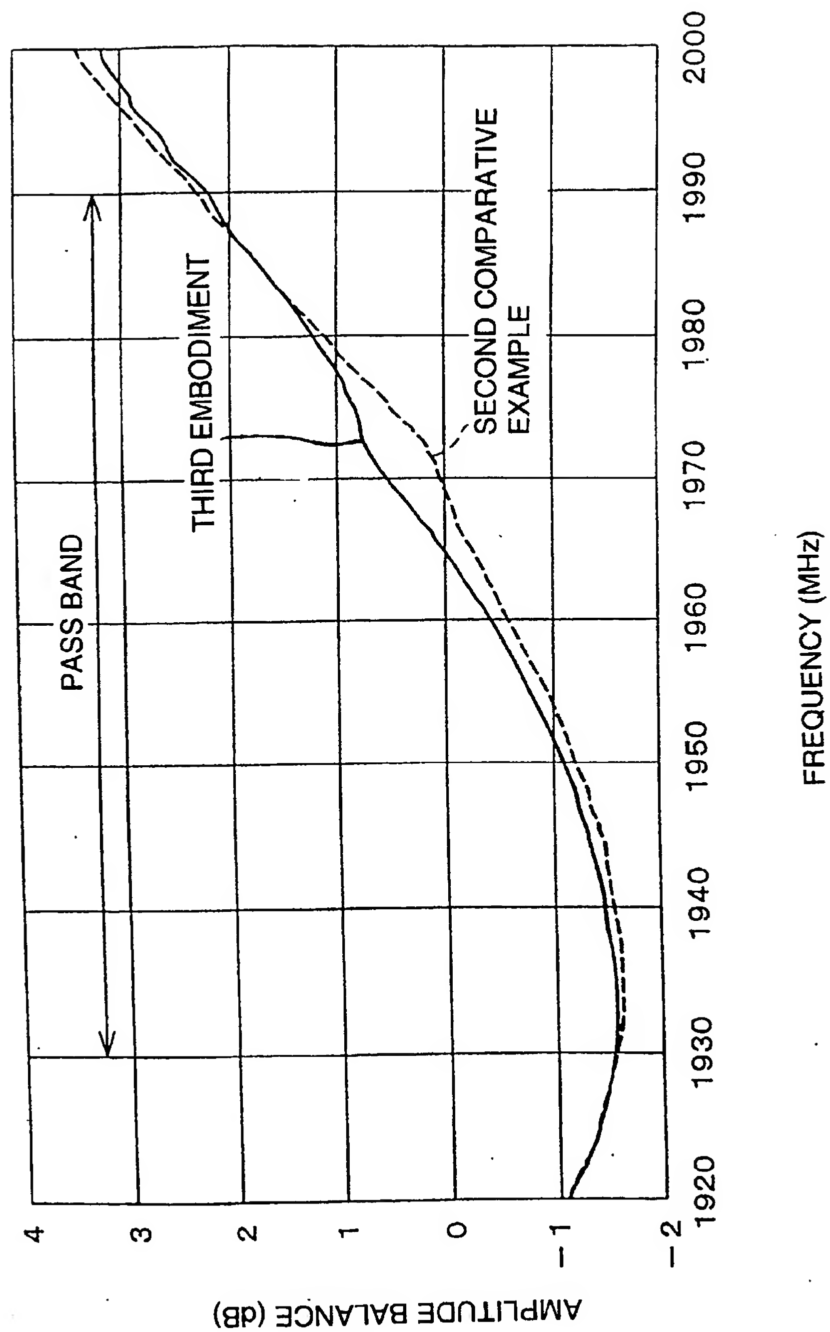

PASS BAND
THIRD EMBODIMENT
SECOND COMPARATIVE EXAMPLE
FREQUENCY (MHz)
AMPLITUDE BALANCE (dB)
1920
1930
1940
1950
1960
1970
1980
1990
2000
4
3
2
1
0
−1
−2

FIG. 31

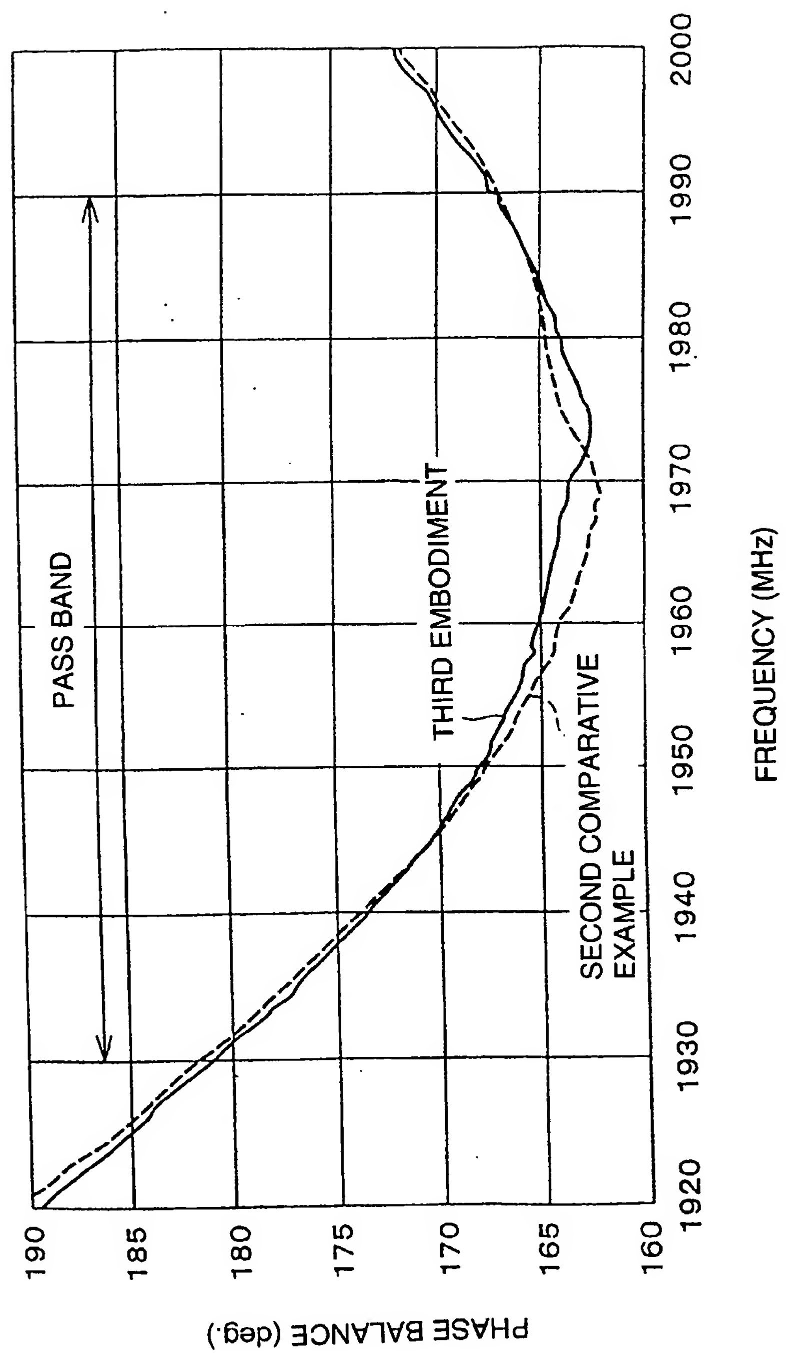

PASS BAND
THIRD EMBODIMENT
SECOND COMPARATIVE EXAMPLE
PHASE BALANCE (deg.)
FREQUENCY (MHz)
190
185
180
175
170
165
160
1920
1930
1940
1950
1960
1970
1980
1990
2000

FIG. 32

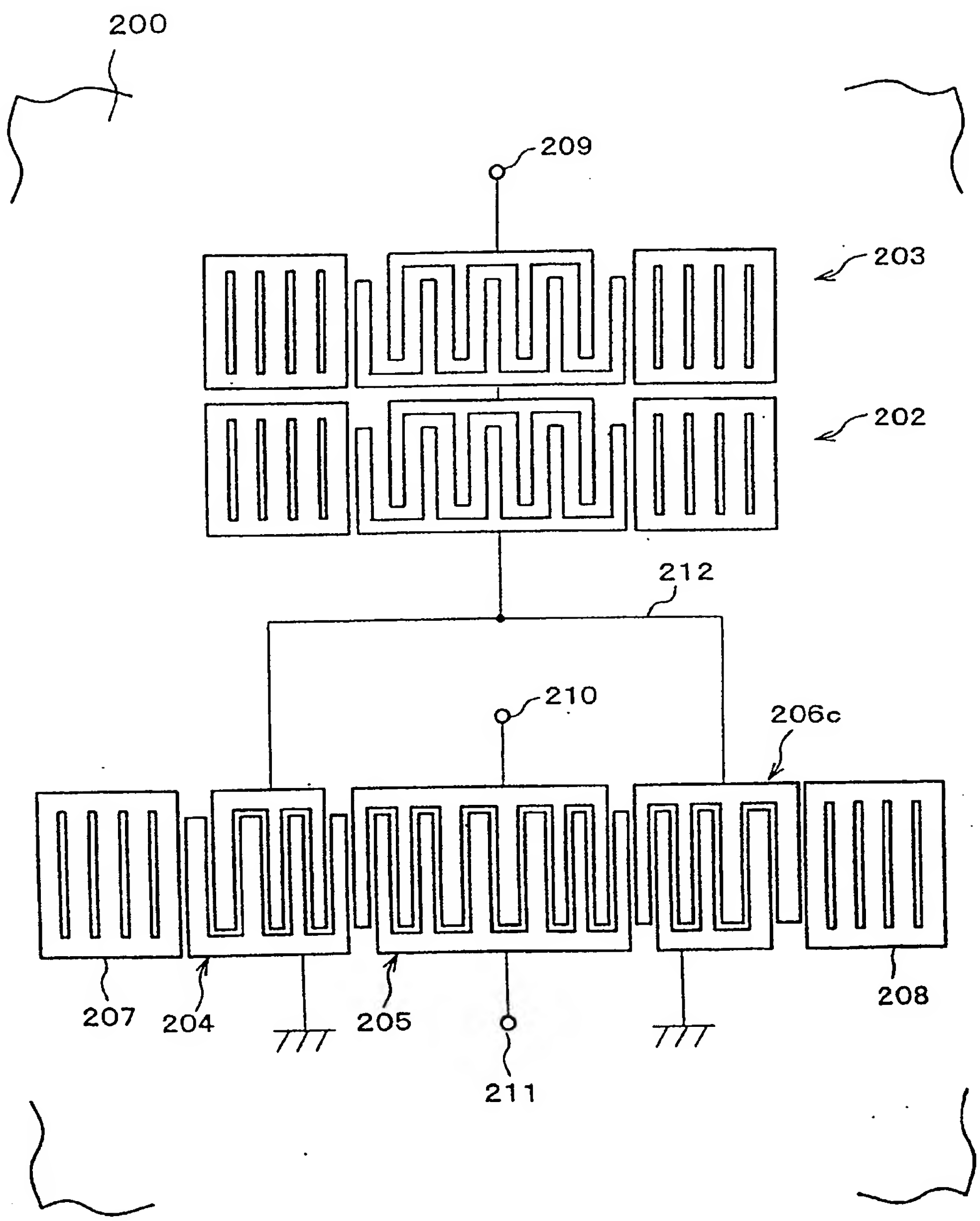


FIG. 33

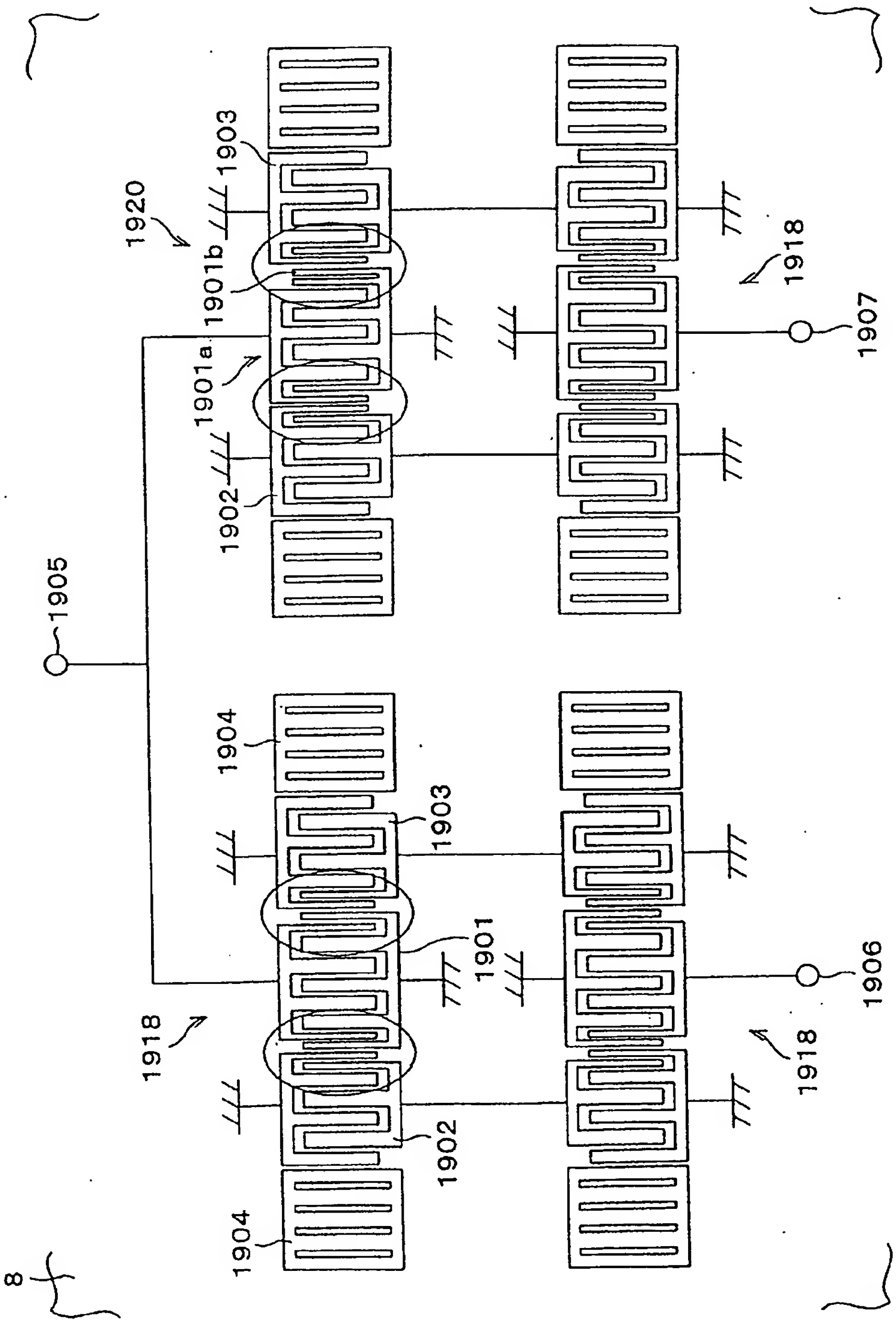

1920
1903
1901b
1901a
1902
1905
1918
1907
1904
1903
1901
1918
1906
1902
1904
8

FIG. 34

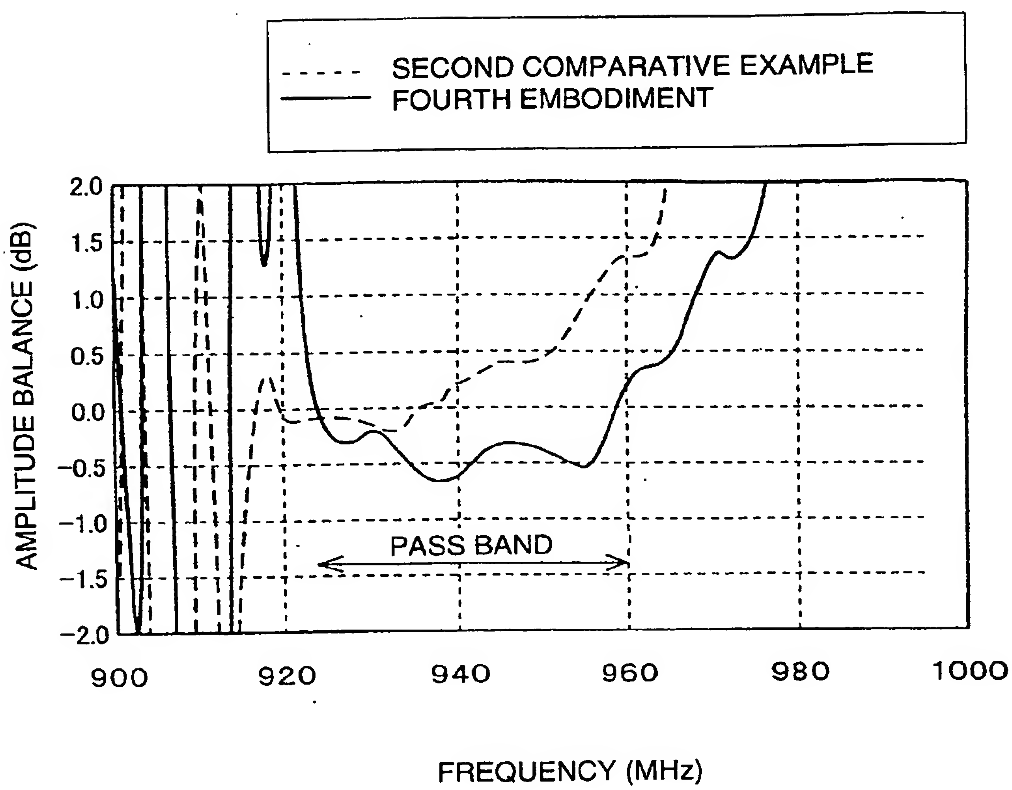

SECOND COMPARATIVE EXAMPLE
FOURTH EMBODIMENT
AMPLITUDE BALANCE (dB)
2.0
1.5
1.0
0.5
0.0
−0.5
−1.0
−1.5
−2.0
PASS BAND
900
920
940
960
980
1000
FREQUENCY (MHz)

FIG. 35

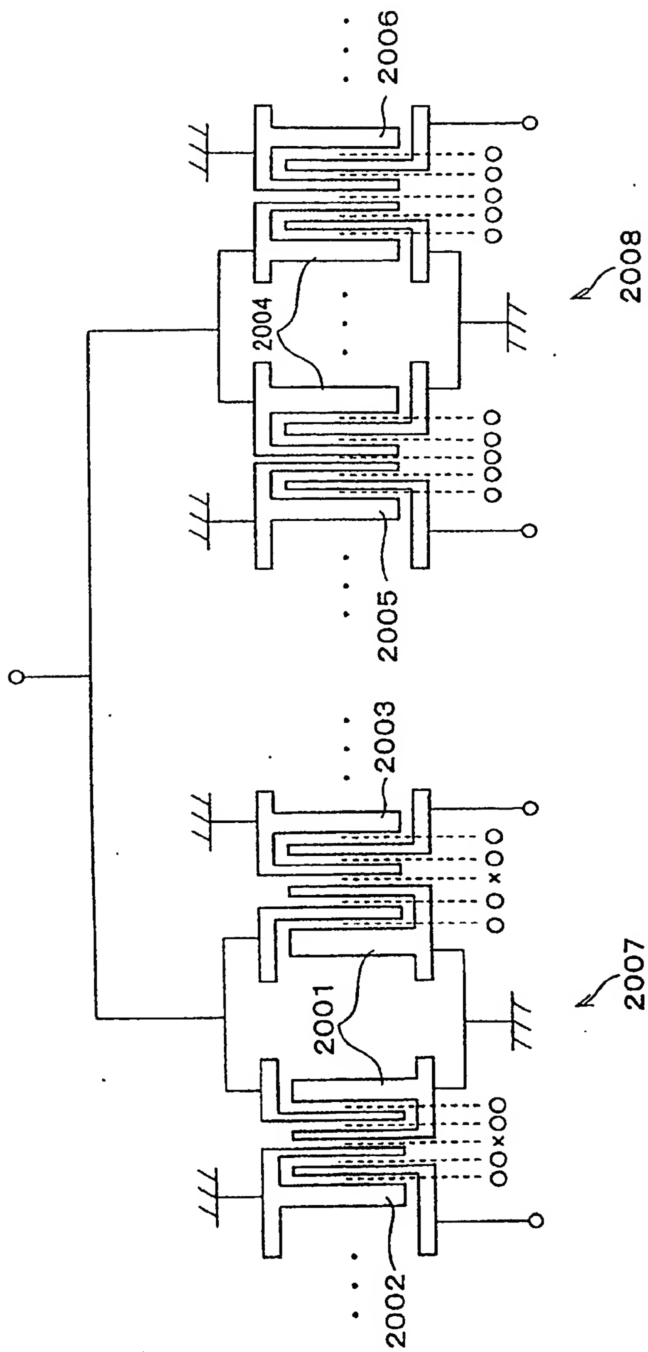


FIG. 36

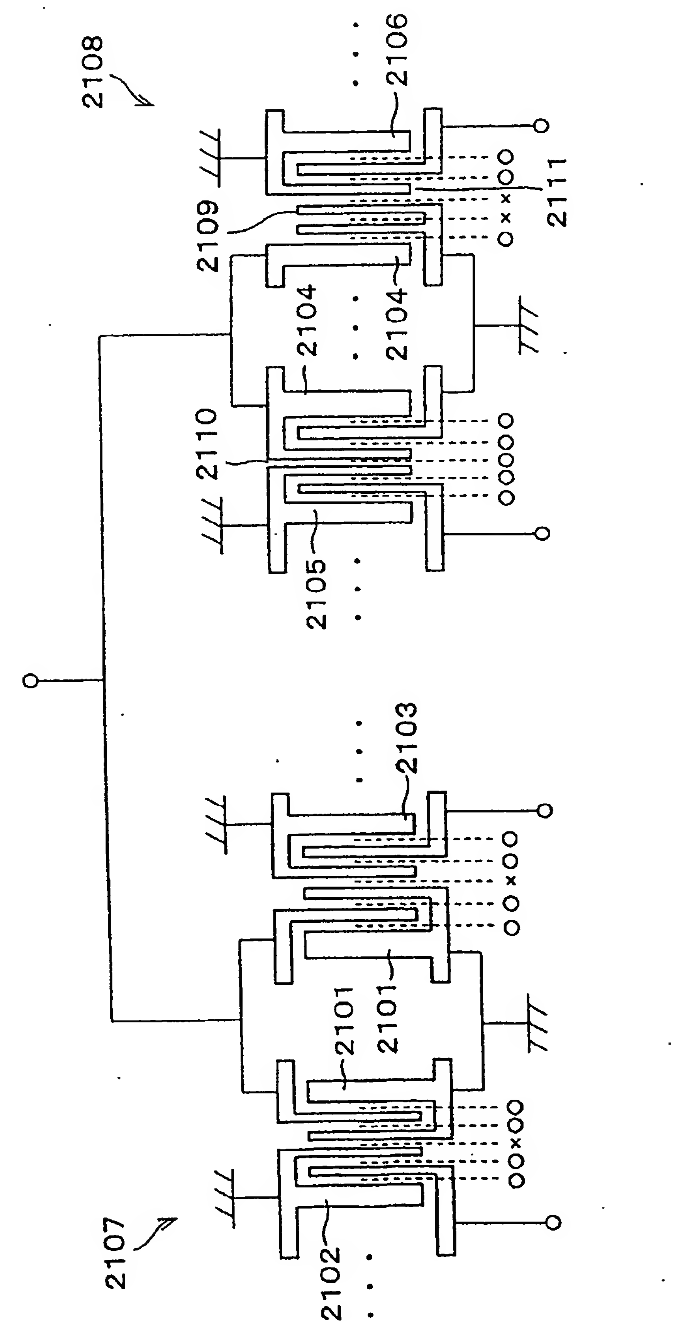


FIG. 37

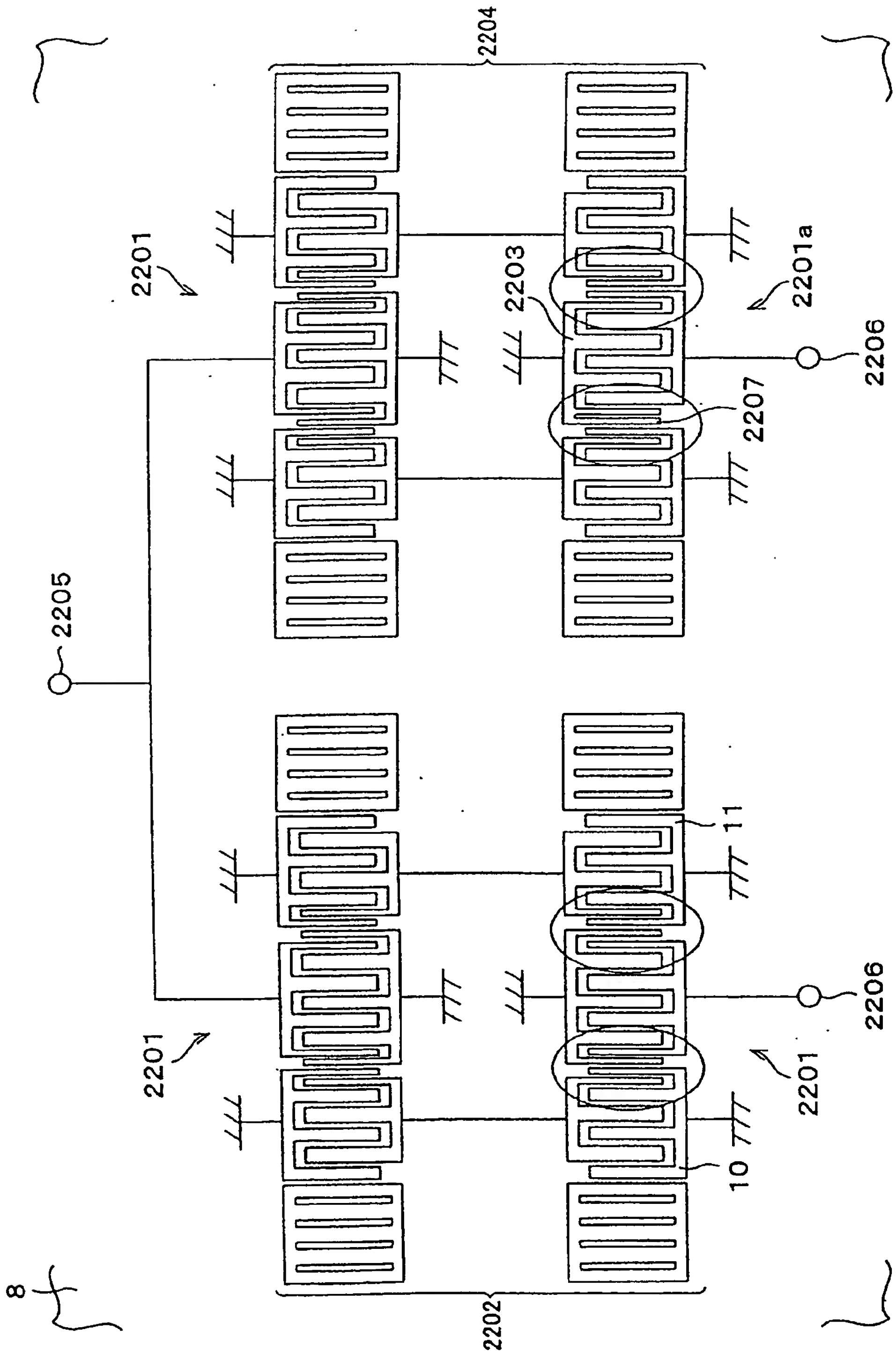

2204
2201
2203
2201a
2206
2207
2205
11
2206
2201
2201
10
8
2202

FIG. 38

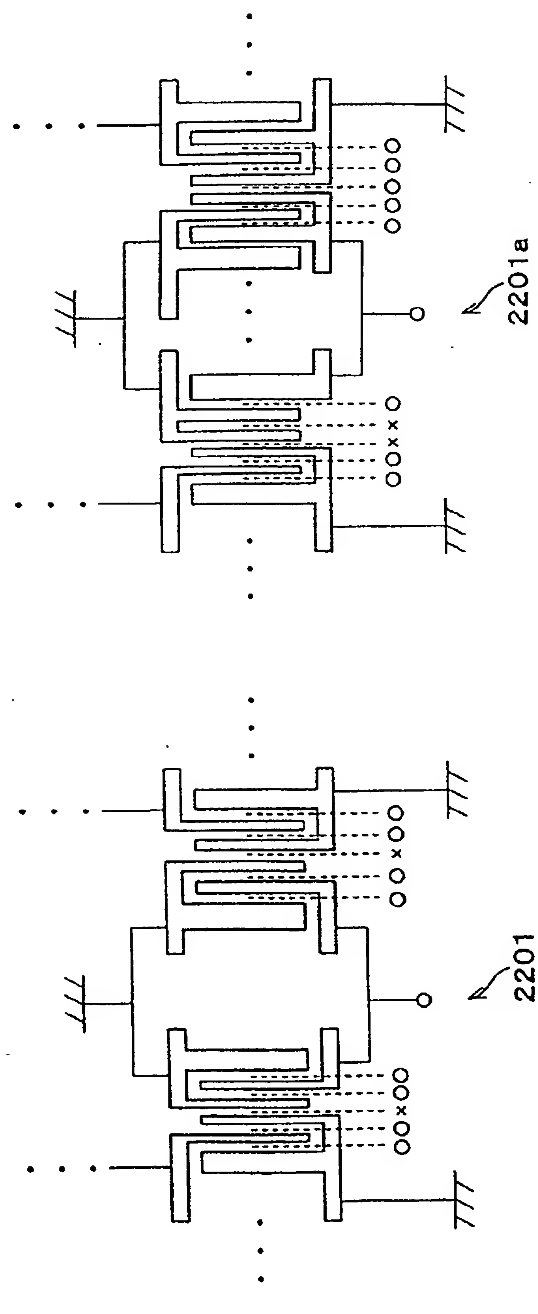


FIG. 39

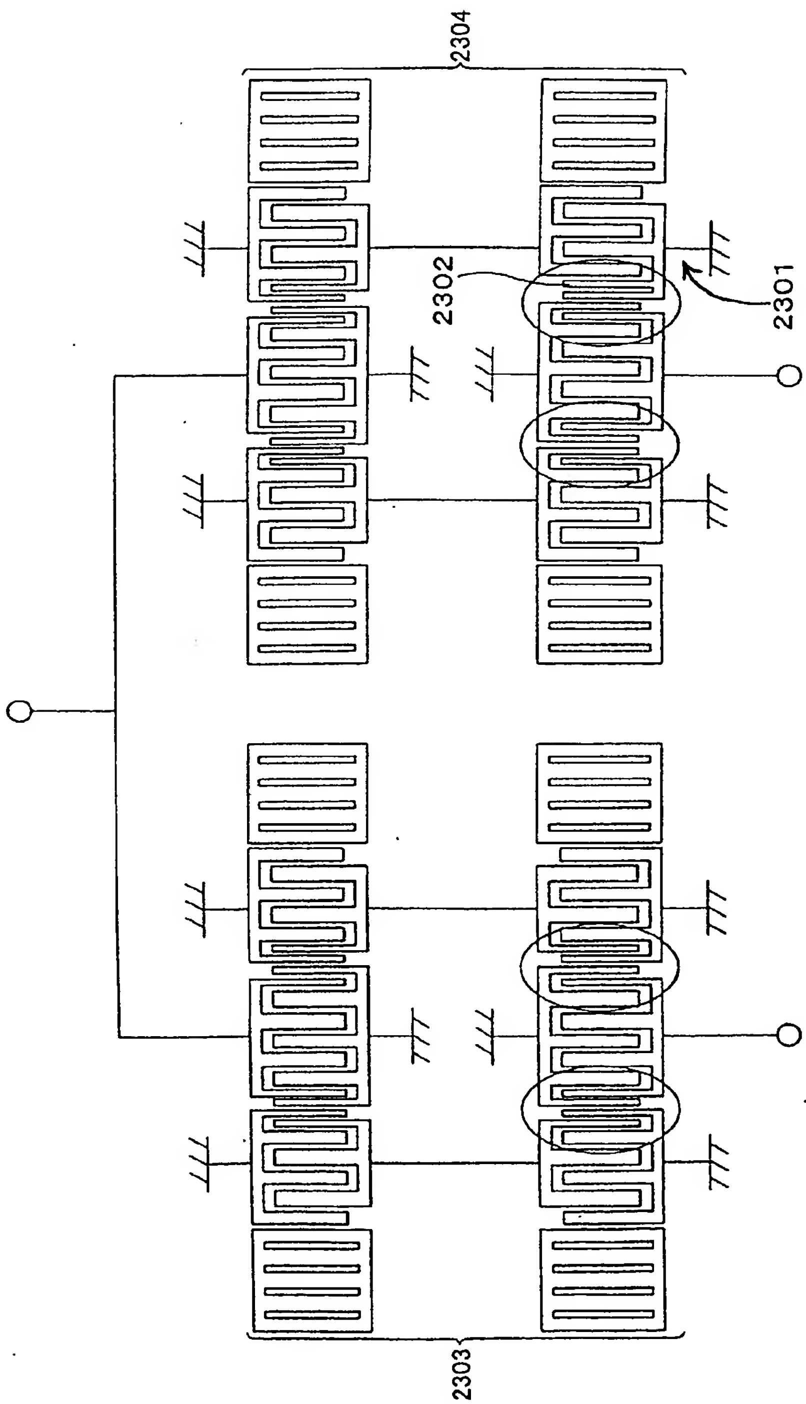


FIG. 40

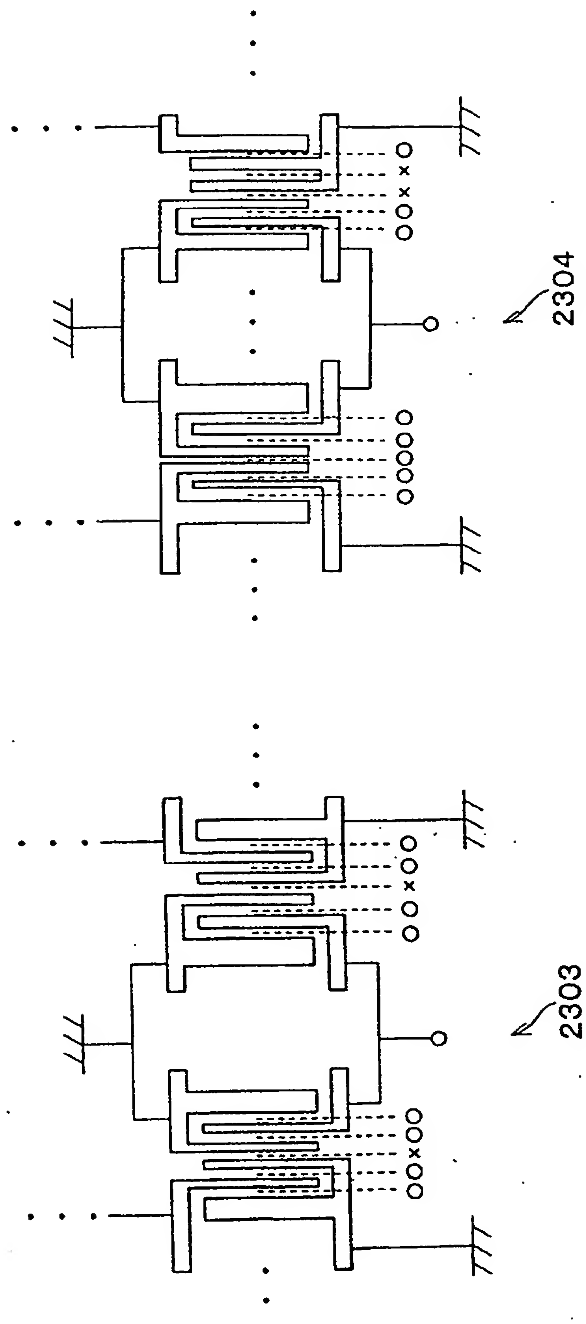


FIG. 41

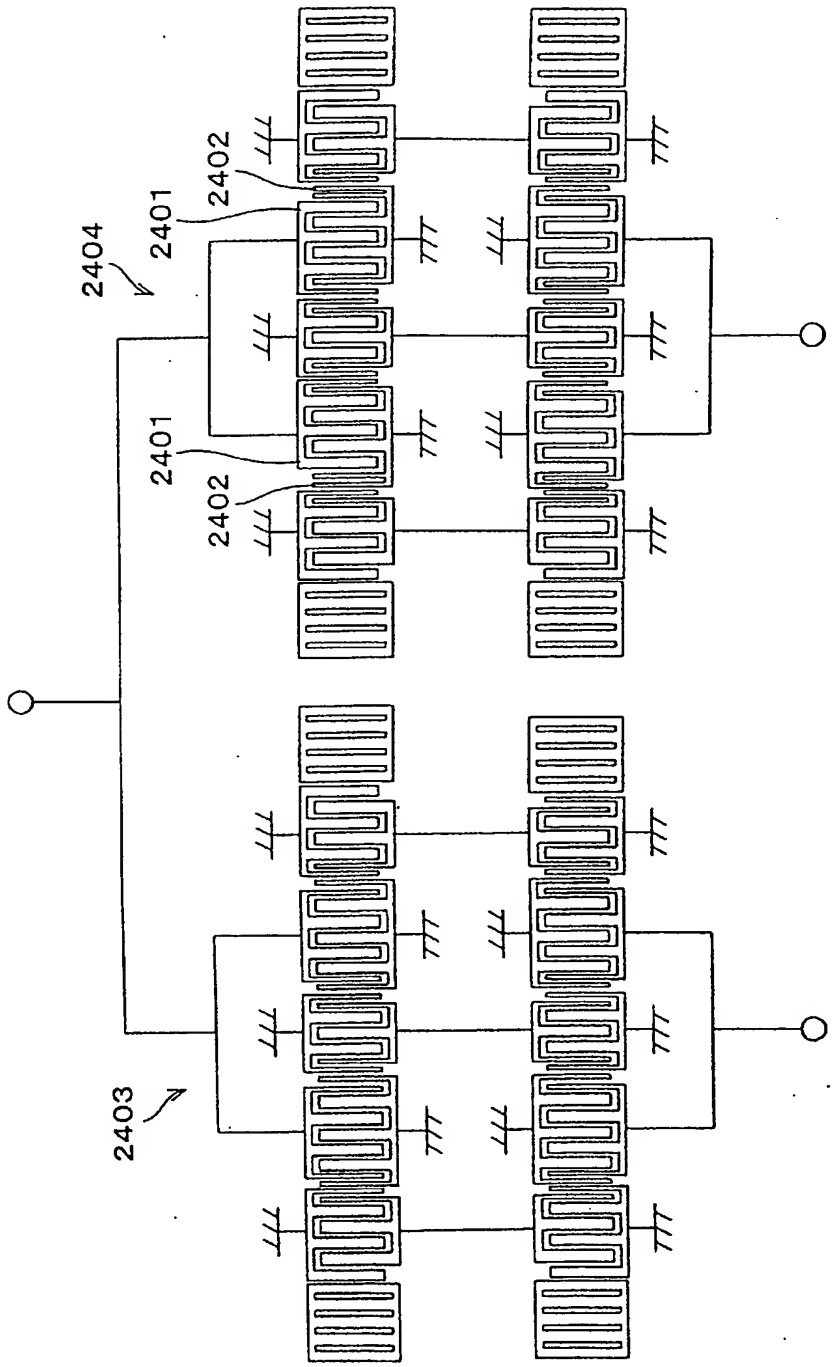


FIG. 42

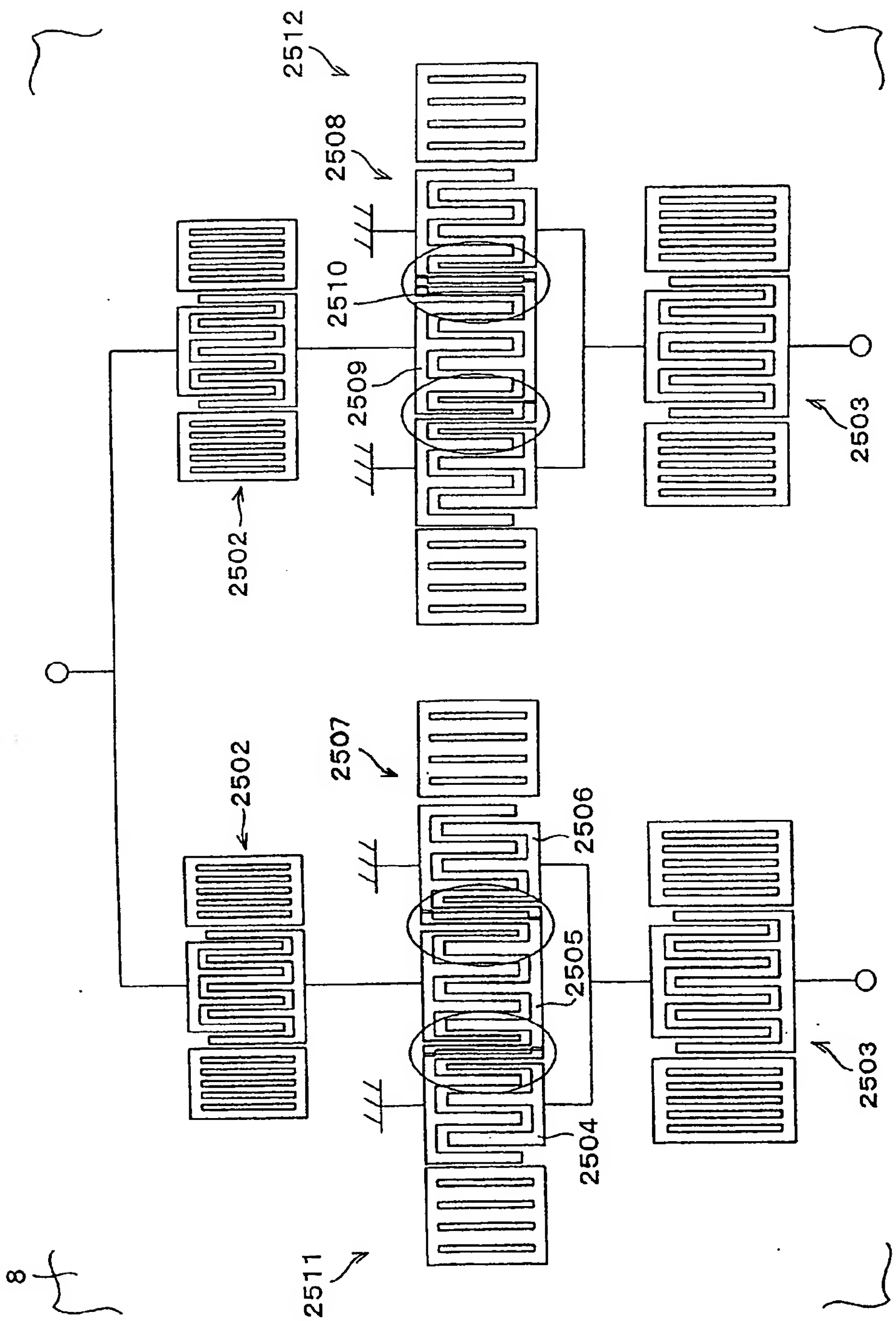


FIG. 43

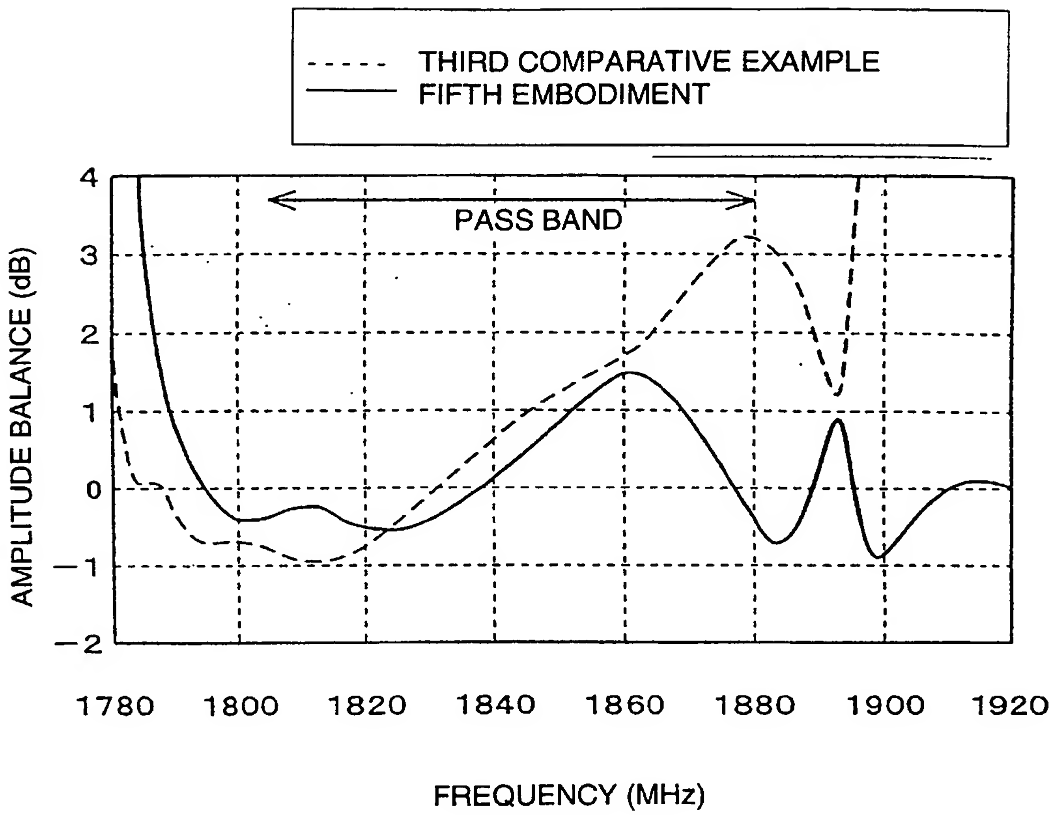

THIRD COMPARATIVE EXAMPLE
FIFTH EMBODIMENT
PASS BAND
AMPLITUDE BALANCE (dB)
4
3
2
1
0
−1
−2
1780
1800
1820
1840
1860
1880
1900
1920
FREQUENCY (MHz)

FIG. 44

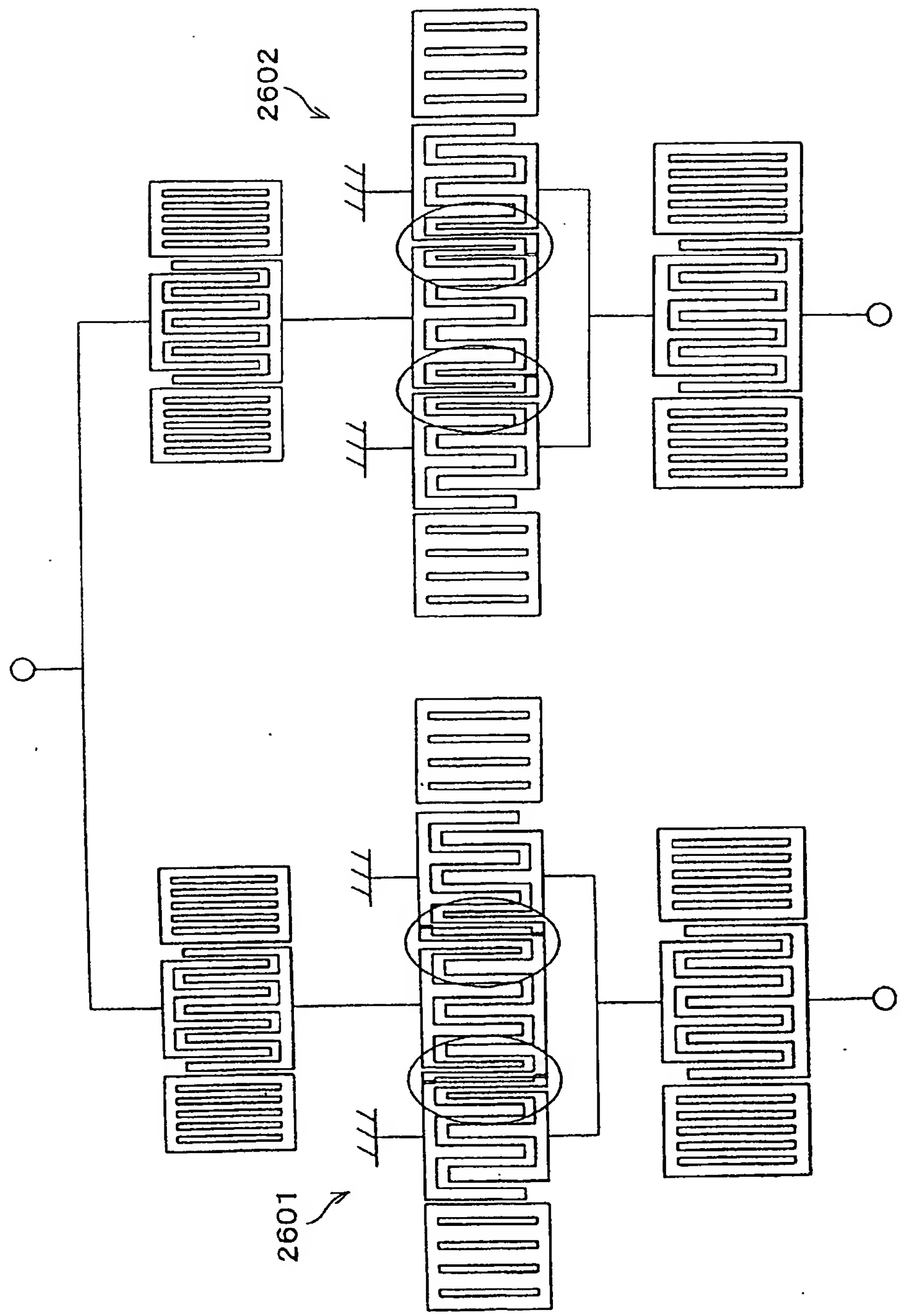


FIG. 45

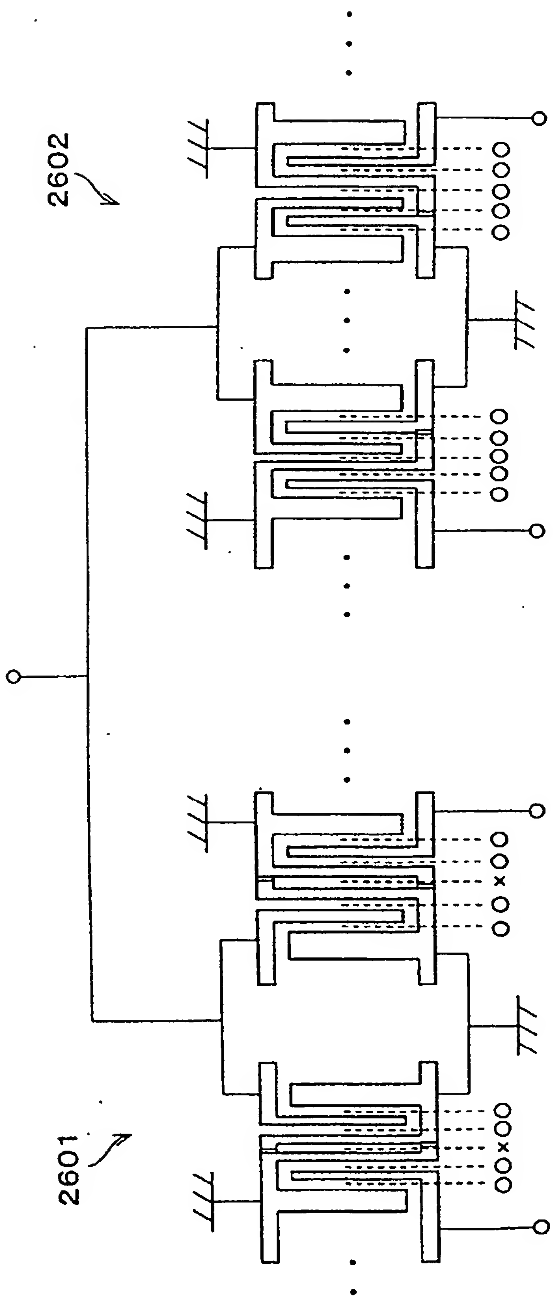


FIG. 46

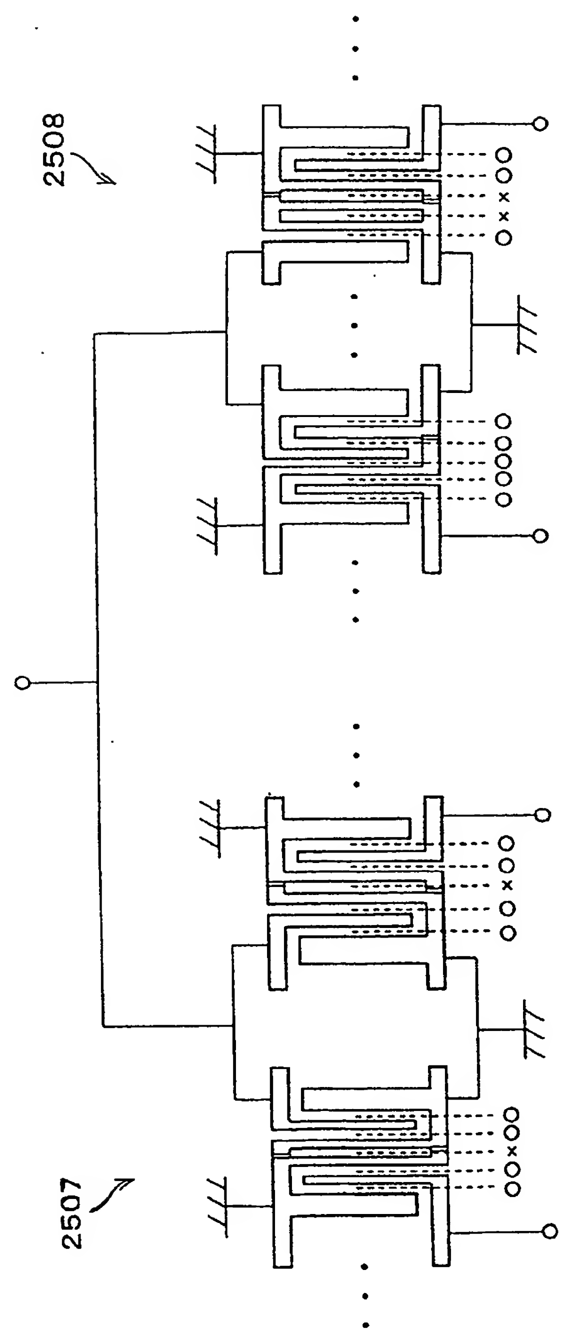
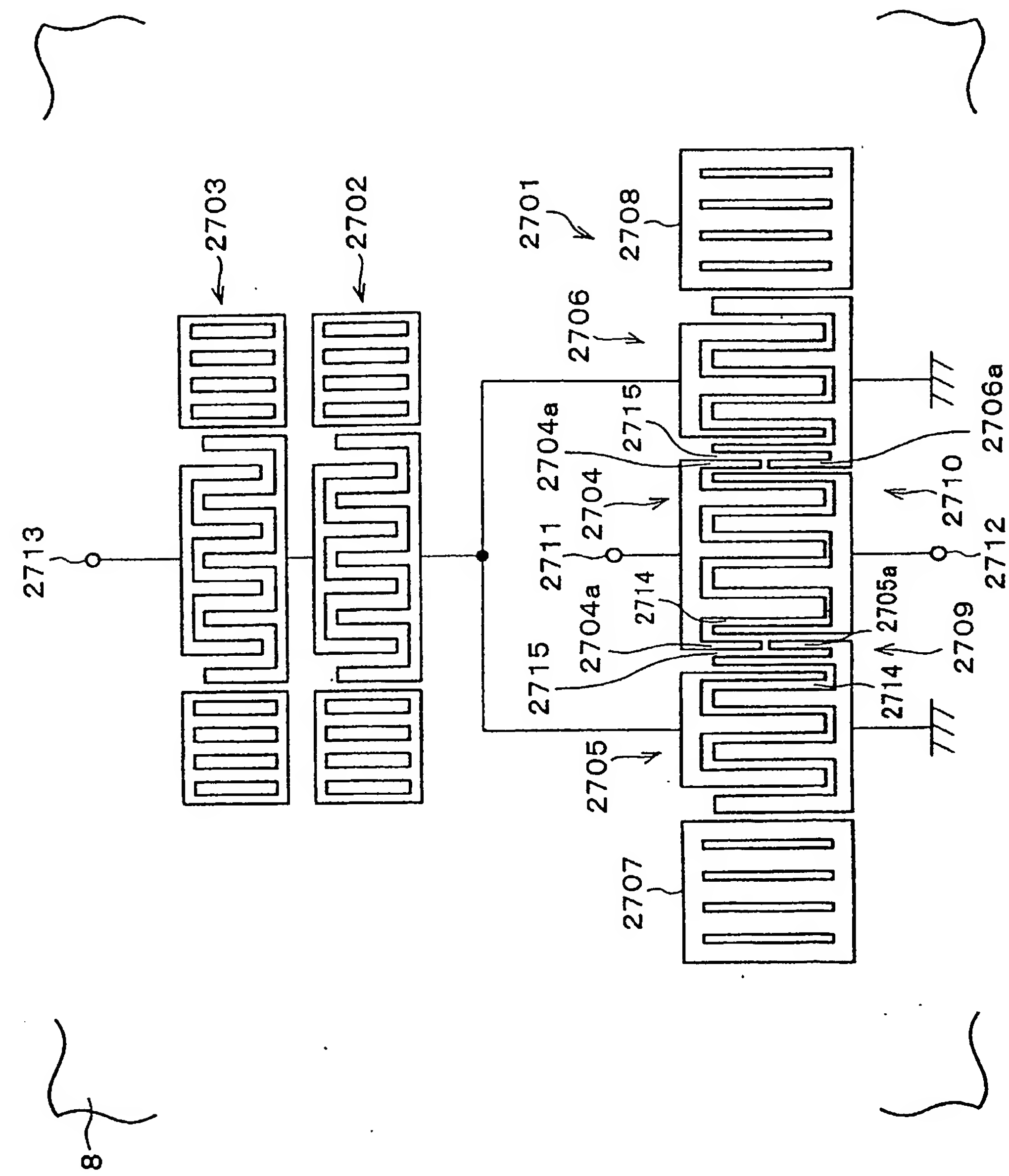


FIG. 47



2713
2703
2702
2701
2708
2706
2715
2704a
2704
2711
2714
2704a
2715
2705
2707
2706a
2710
2712
2705a
2709
2714
8

FIG. 48

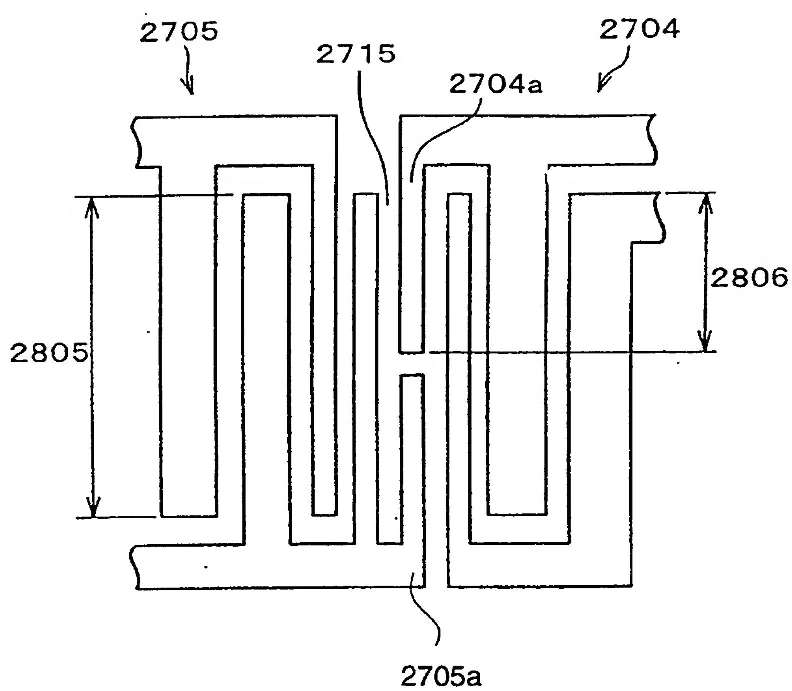


FIG. 49

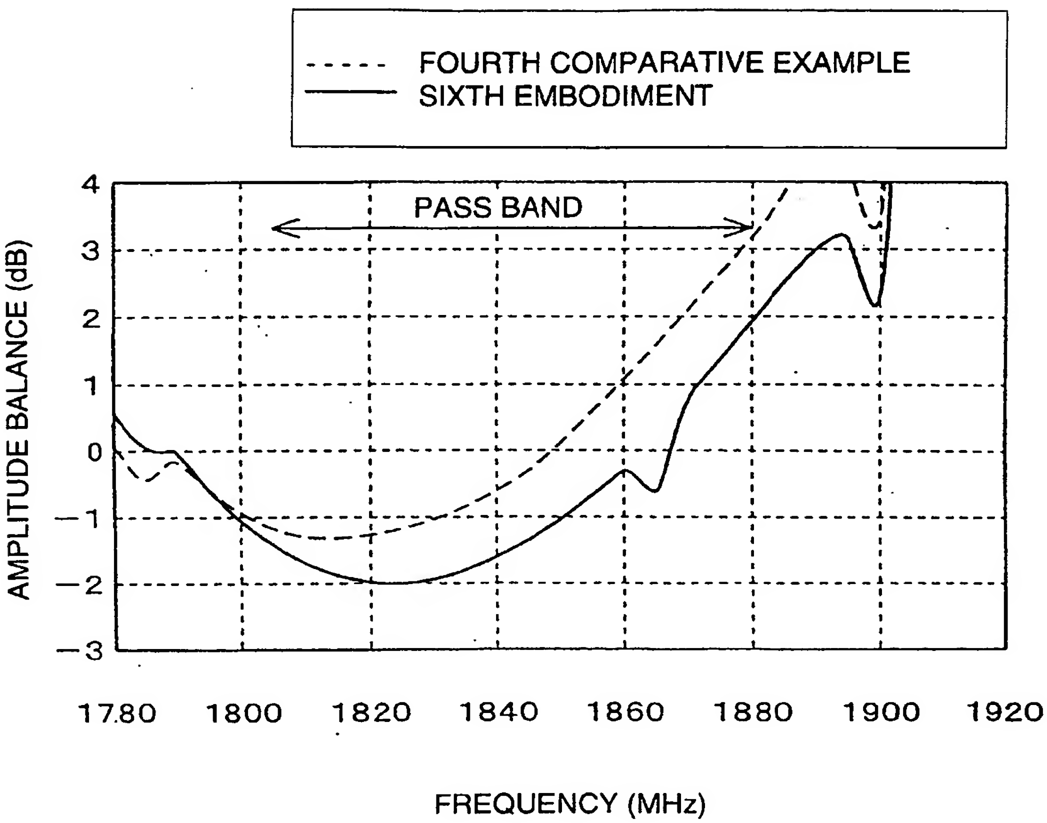

FOURTH COMPARATIVE EXAMPLE
SIXTH EMBODIMENT
PASS BAND
AMPLITUDE BALANCE (dB)
4
3
2
1
0
−1
−2
−3
17.80
1800
1820
1840
1860
1880
1900
1920
FREQUENCY (MHz)

FIG. 50

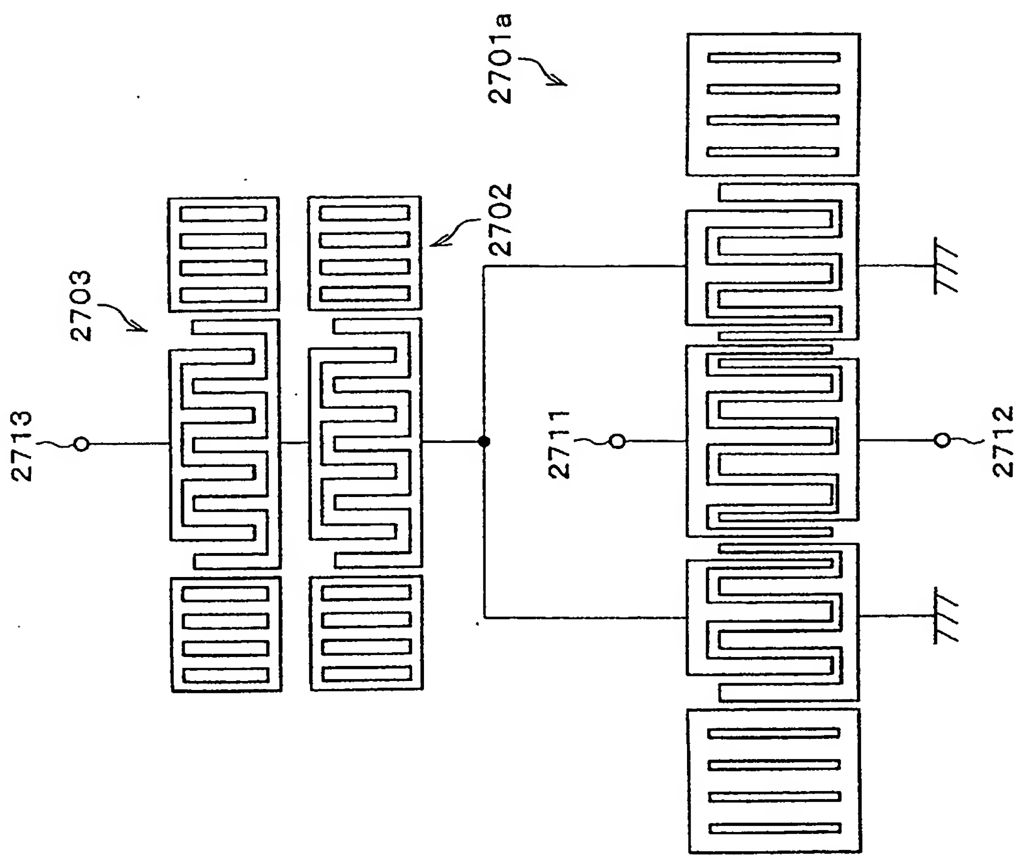


FIG. 51

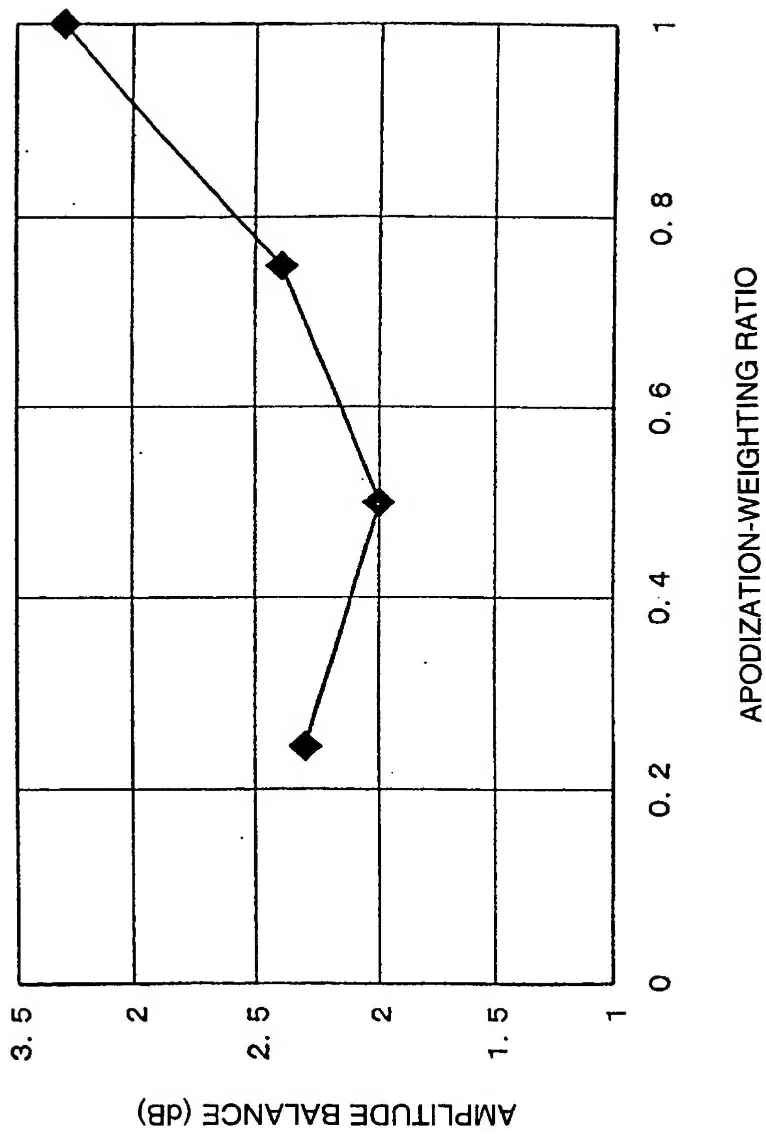

AMPLITUDE BALANCE (dB)
3.5
2.5
2
1.5
1
APODIZATION-WEIGHTING RATIO
0
0.2
0.4
0.6
0.8
1

FIG. 52

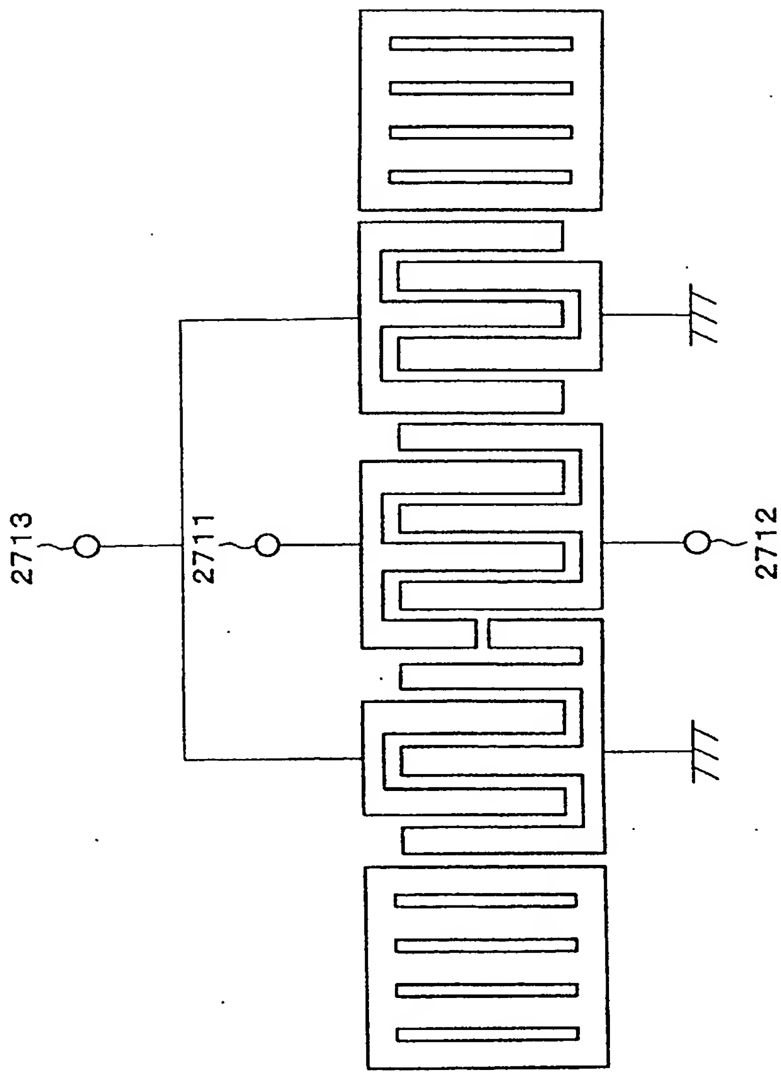


FIG. 53

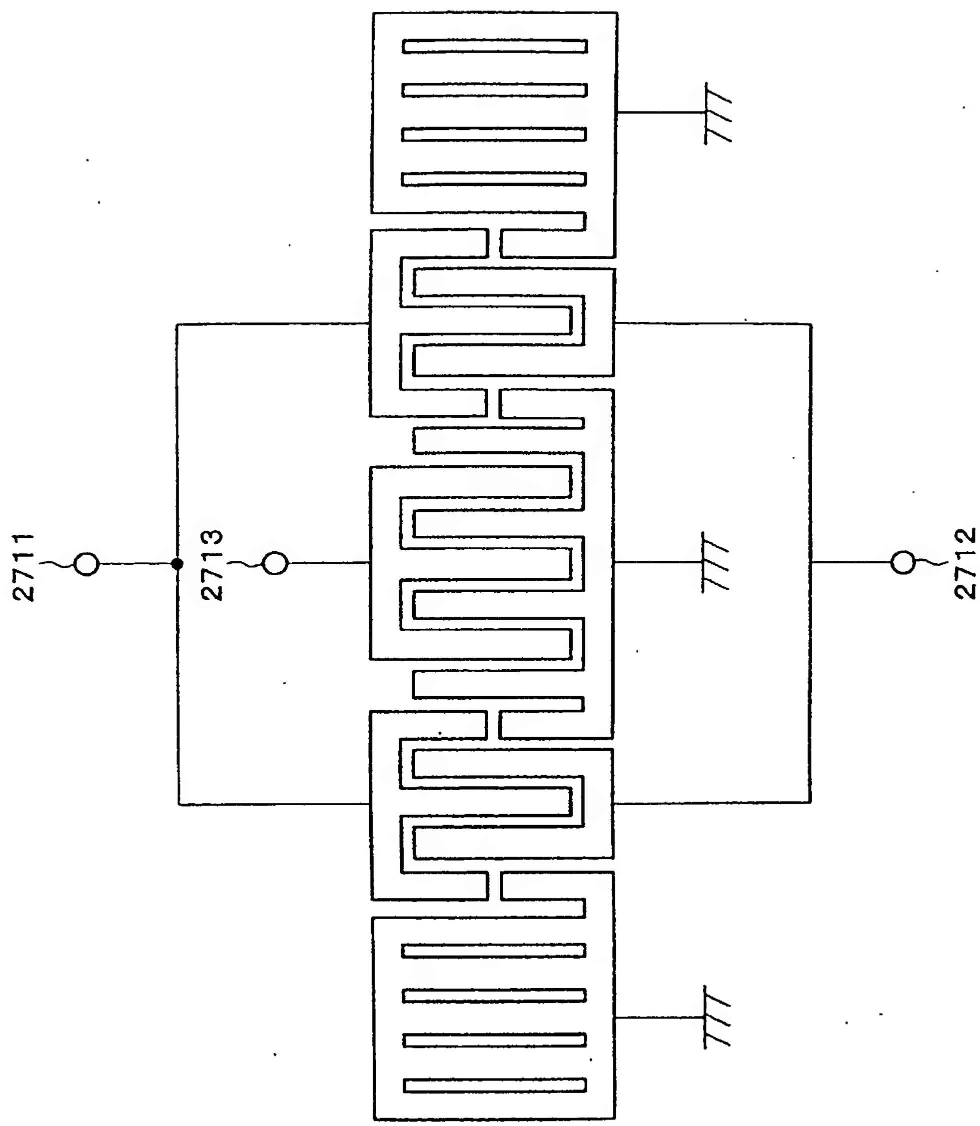


FIG. 54

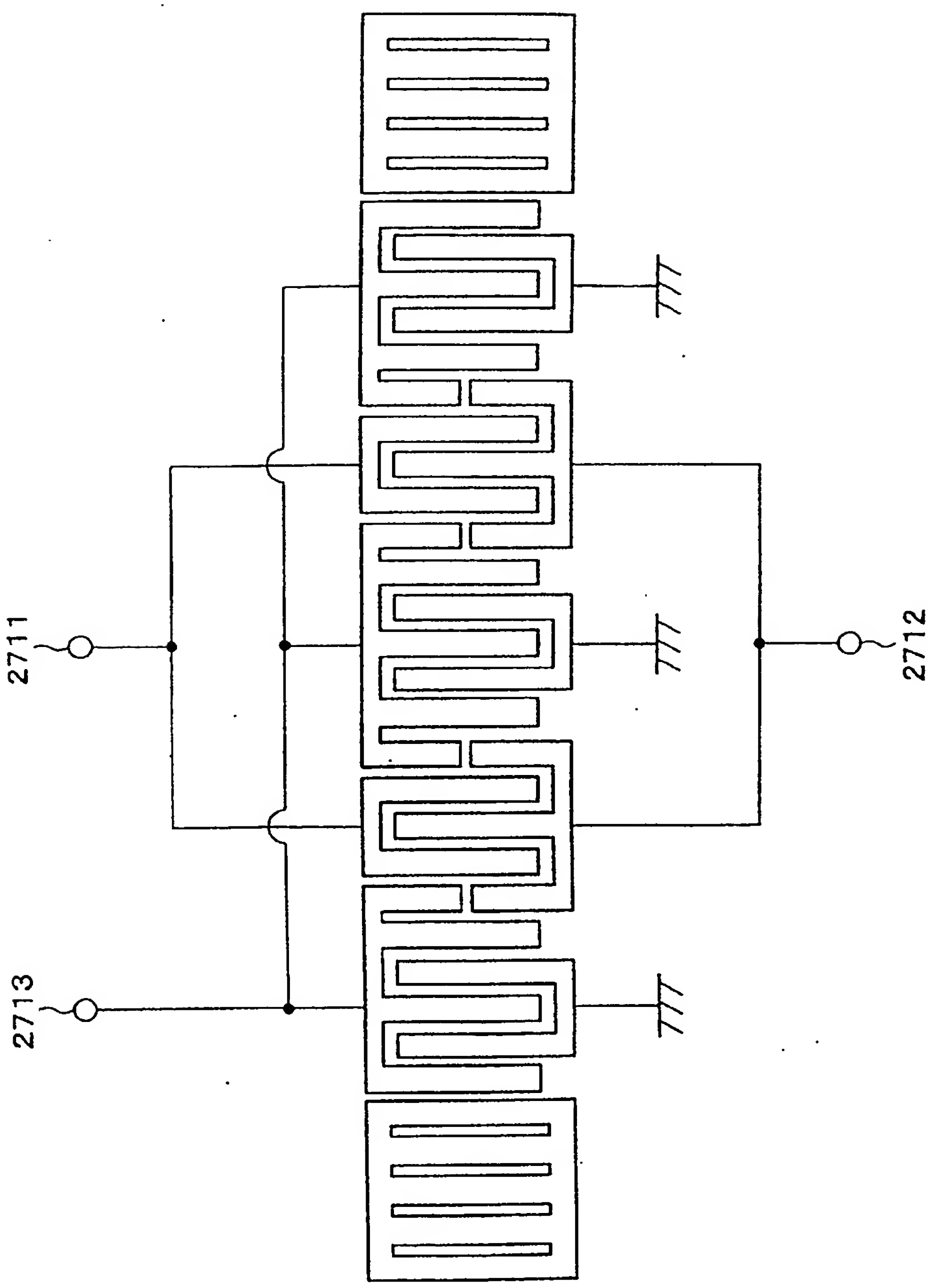


FIG. 55

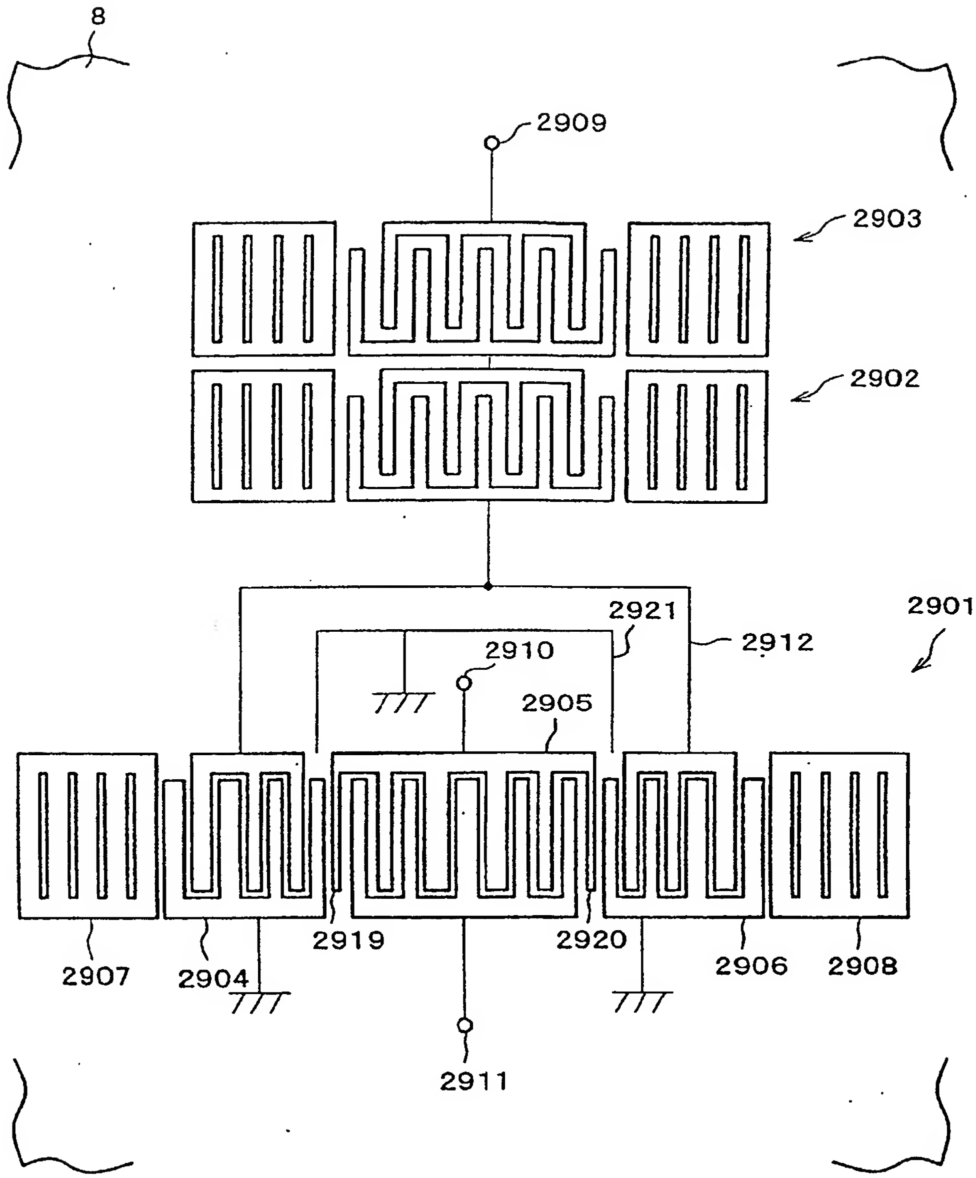
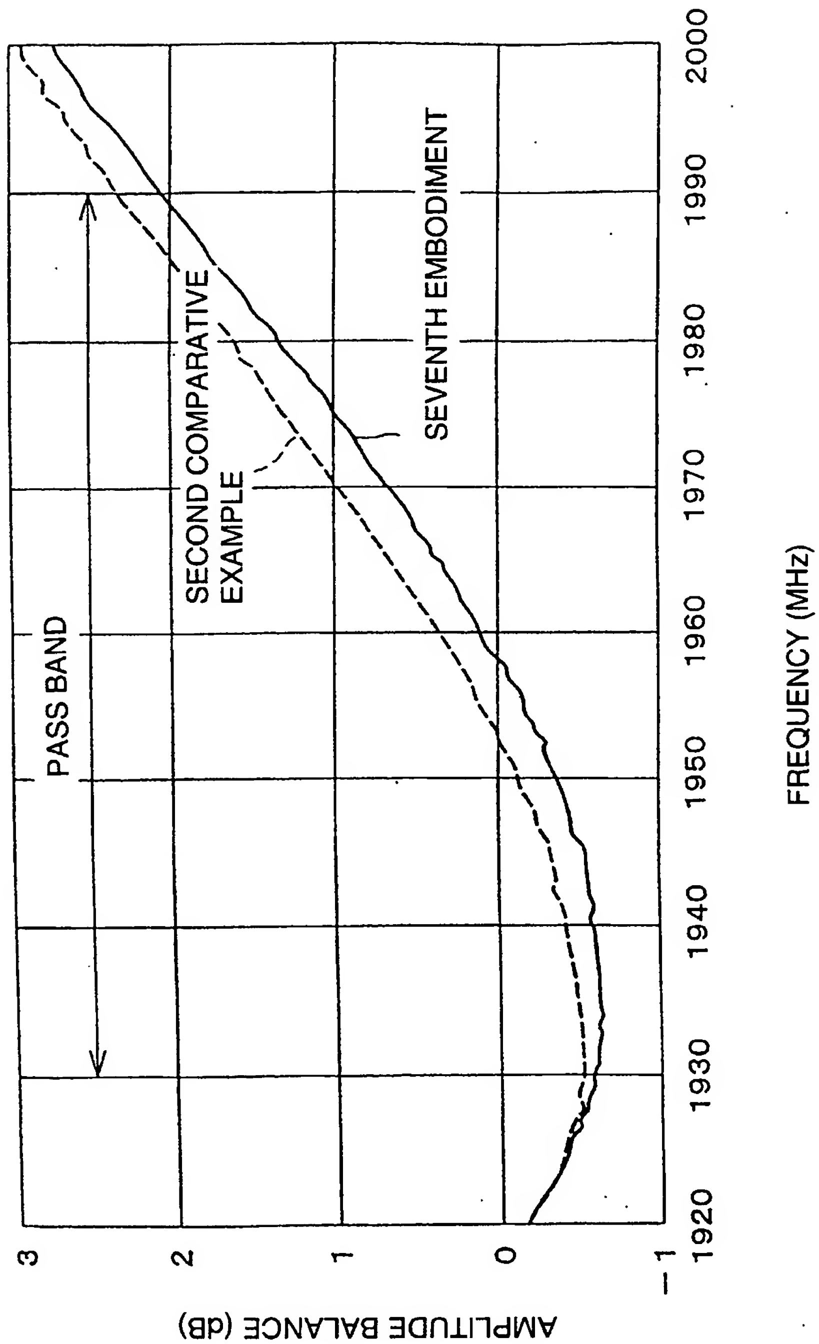

8
2909
2903
2902
2921
2901
2910
2912
2905
2919
2920
2907
2904
2906
2908
2911

FIG. 56



AMPLITUDE BALANCE (dB)
FREQUENCY (MHz)
PASS BAND
SECOND COMPARATIVE EXAMPLE
SEVENTH EMBODIMENT
3
2
1
0
−1
1920
1930
1940
1950
1960
1970
1980
1990
2000

FIG. 57

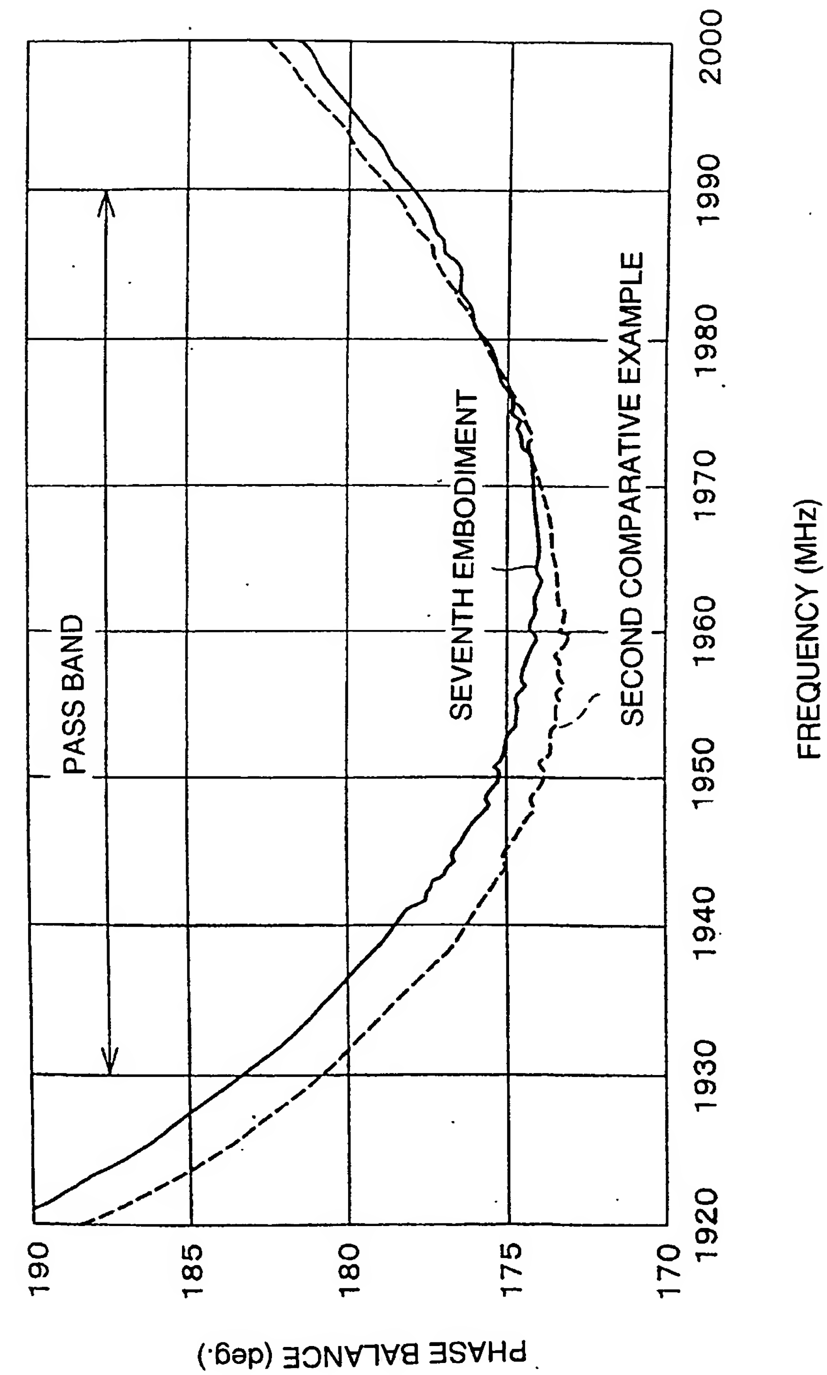

PASS BAND
SEVENTH EMBODIMENT
SECOND COMPARATIVE EXAMPLE
FREQUENCY (MHz)
PHASE BALANCE (deg.)
1920
1930
1940
1950
1960
1970
1980
1990
2000
190
185
180
175
170

FIG. 58

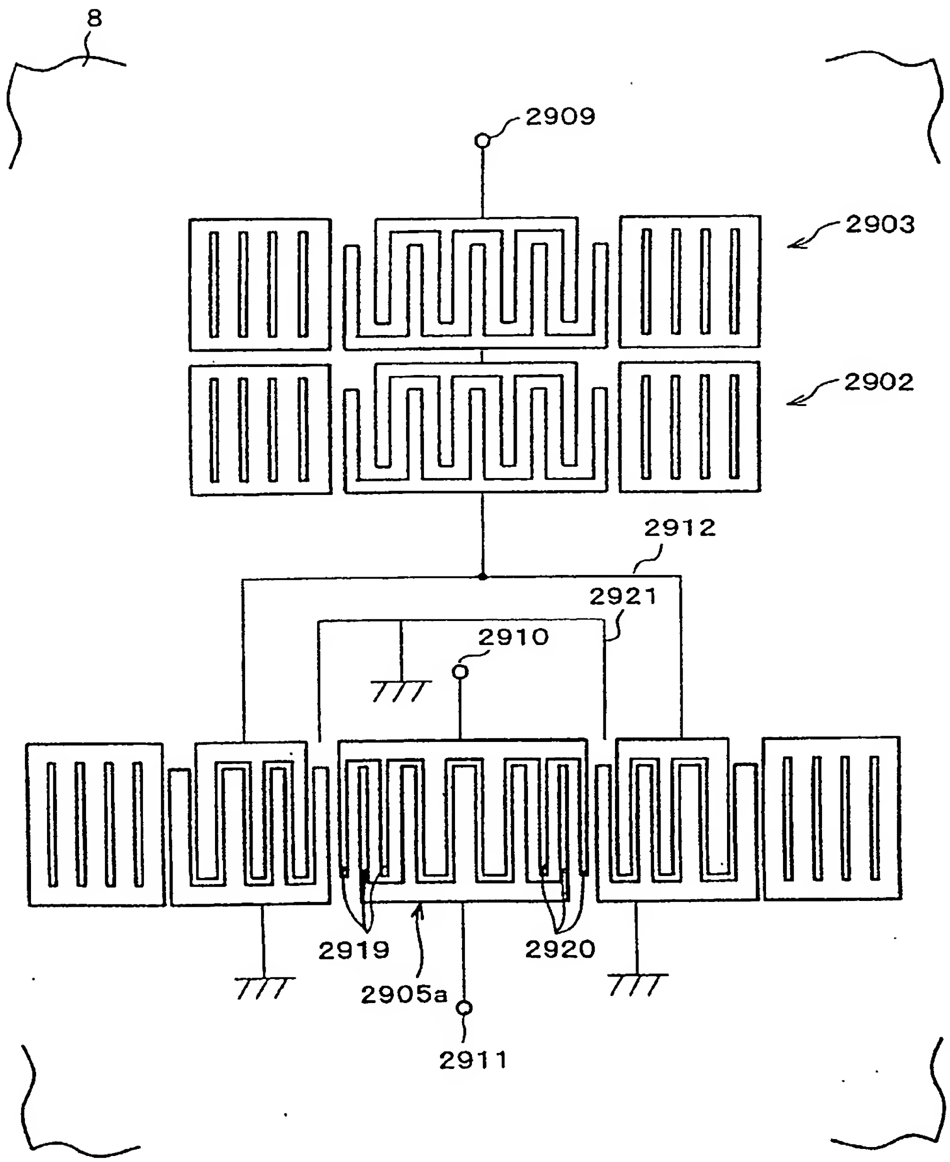


FIG. 59

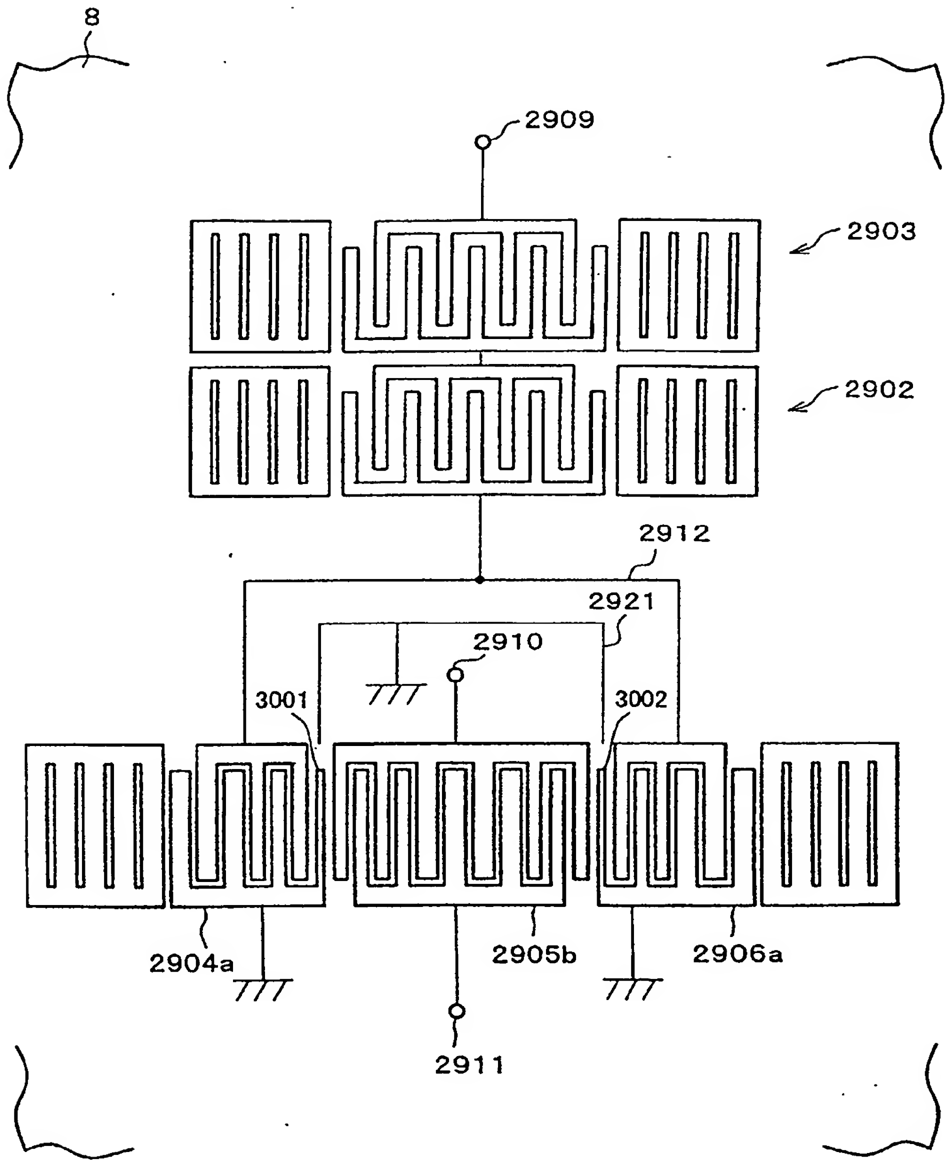

8
2909
2903
2902
2912
2921
2910
3001
3002
2904a
2905b
2906a
2911

FIG. 60

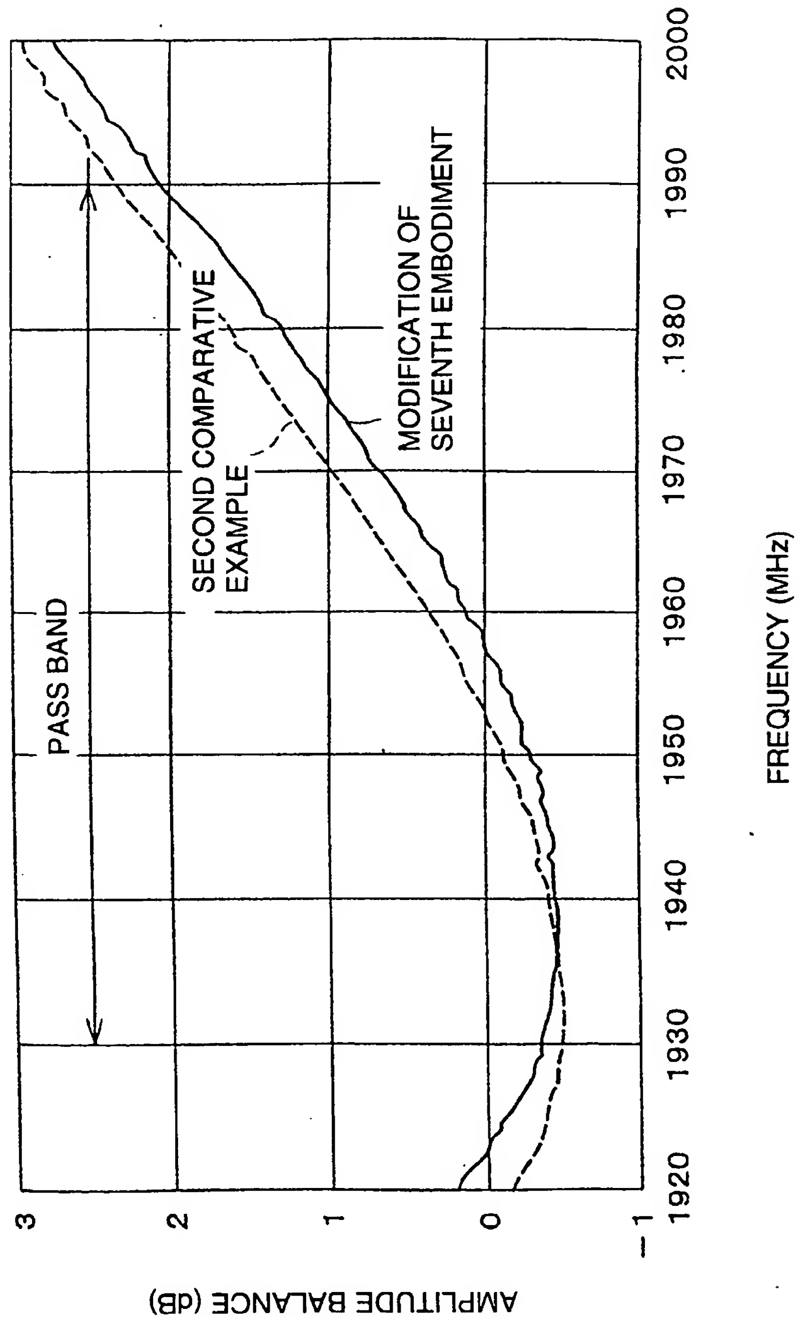

PASS BAND
SECOND COMPARATIVE EXAMPLE
MODIFICATION OF SEVENTH EMBODIMENT
AMPLITUDE BALANCE (dB)
3
2
1
0
−1
FREQUENCY (MHz)
1920
1930
1940
1950
1960
1970
1980
1990
2000

FIG. 61

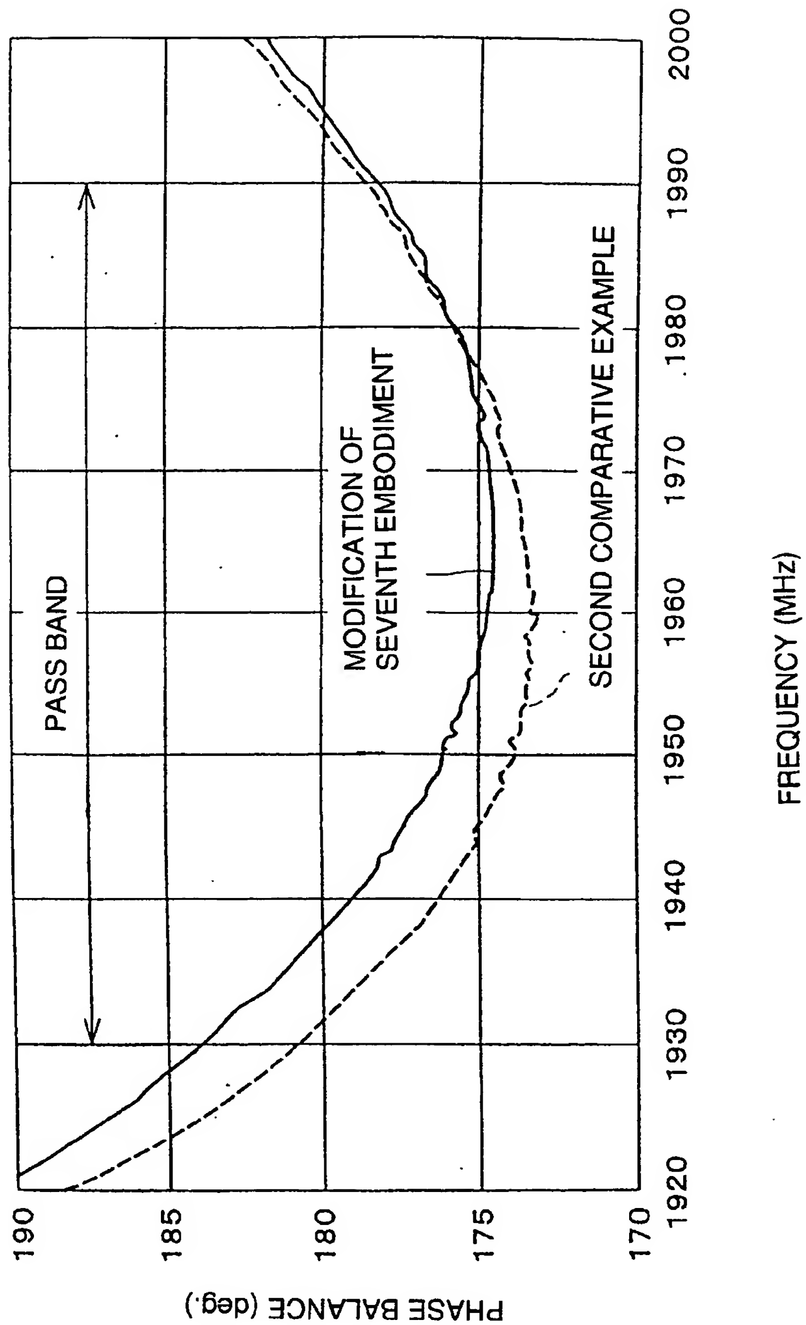

PASS BAND
MODIFICATION OF
SEVENTH EMBODIMENT
SECOND COMPARATIVE EXAMPLE
FREQUENCY (MHz)
PHASE BALANCE (deg.)
1920
1930
1940
1950
1960
1970
1980
1990
2000
190
185
180
175
170

FIG. 62

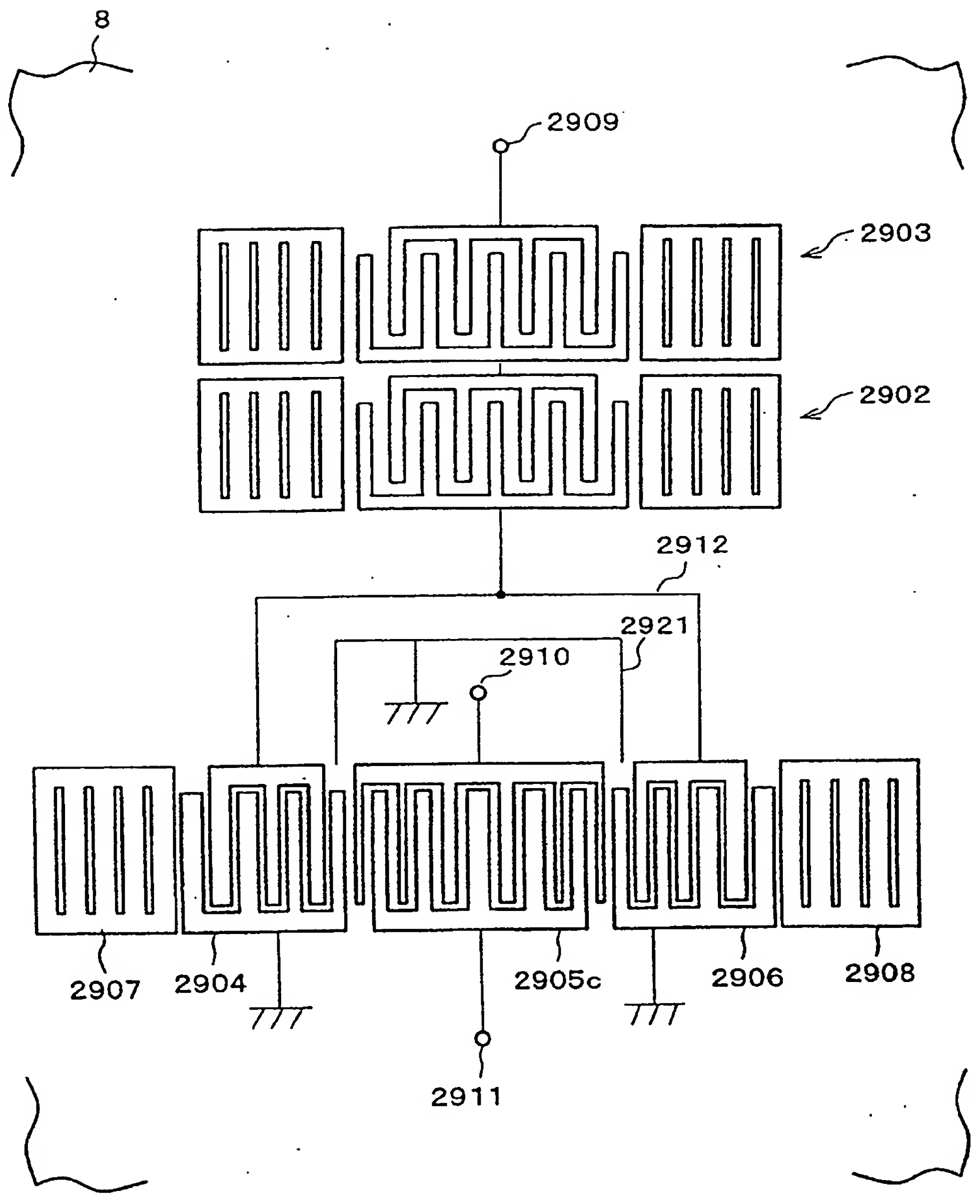

8
2909
2903
2902
2912
2921
2910
2907
2904
2905c
2906
2908
2911

FIG. 63

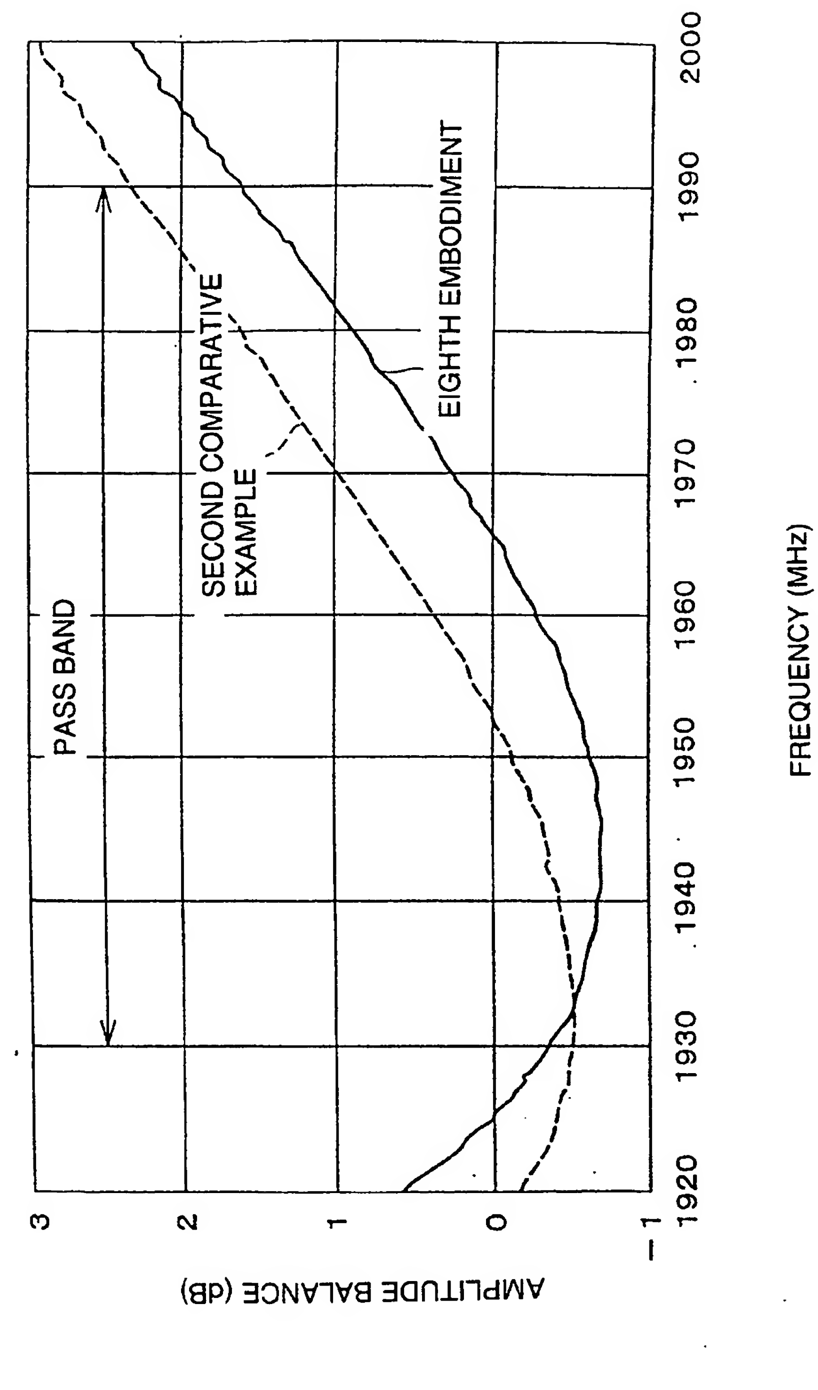

PASS BAND
SECOND COMPARATIVE EXAMPLE
EIGHTH EMBODIMENT
AMPLITUDE BALANCE (dB)
FREQUENCY (MHz)
3
2
1
0
−1
1920
1930
1940
1950
1960
1970
1980
1990
2000

FIG. 64

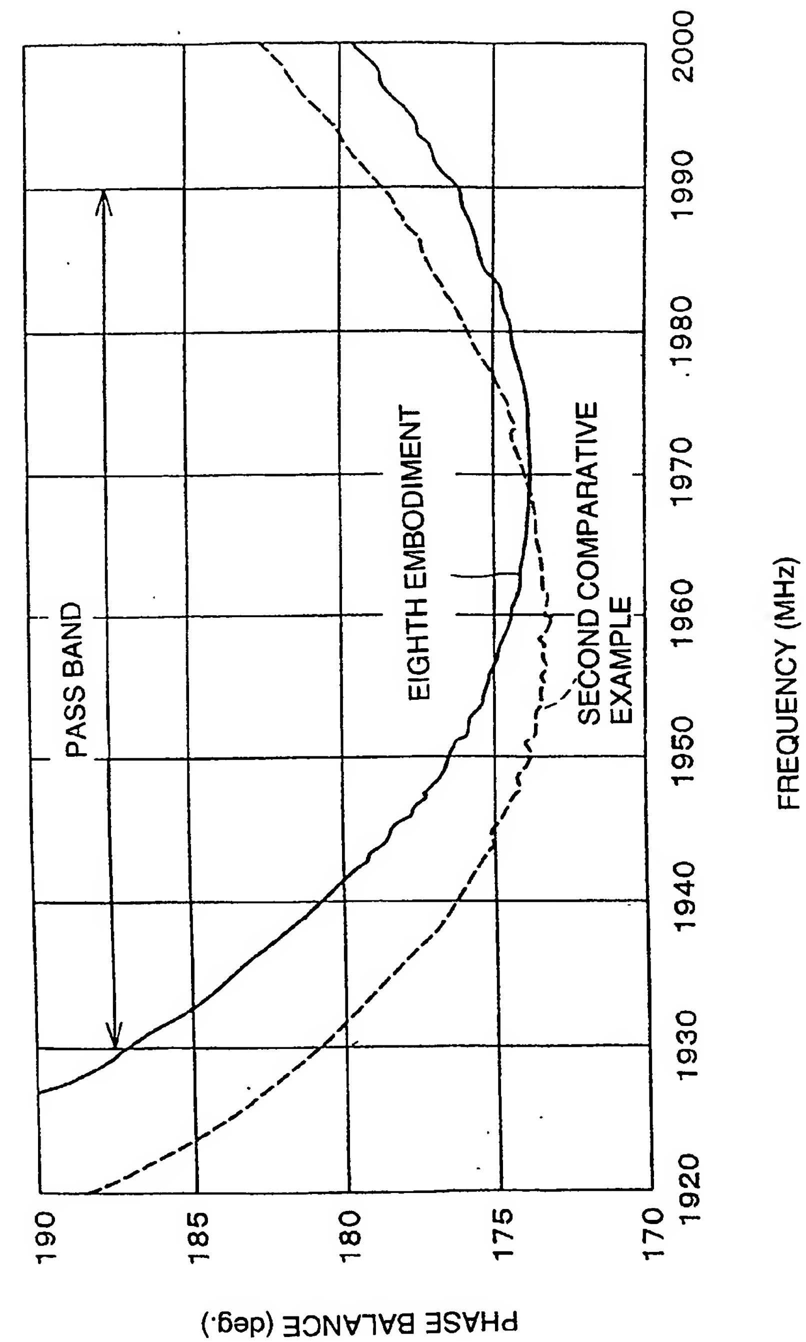
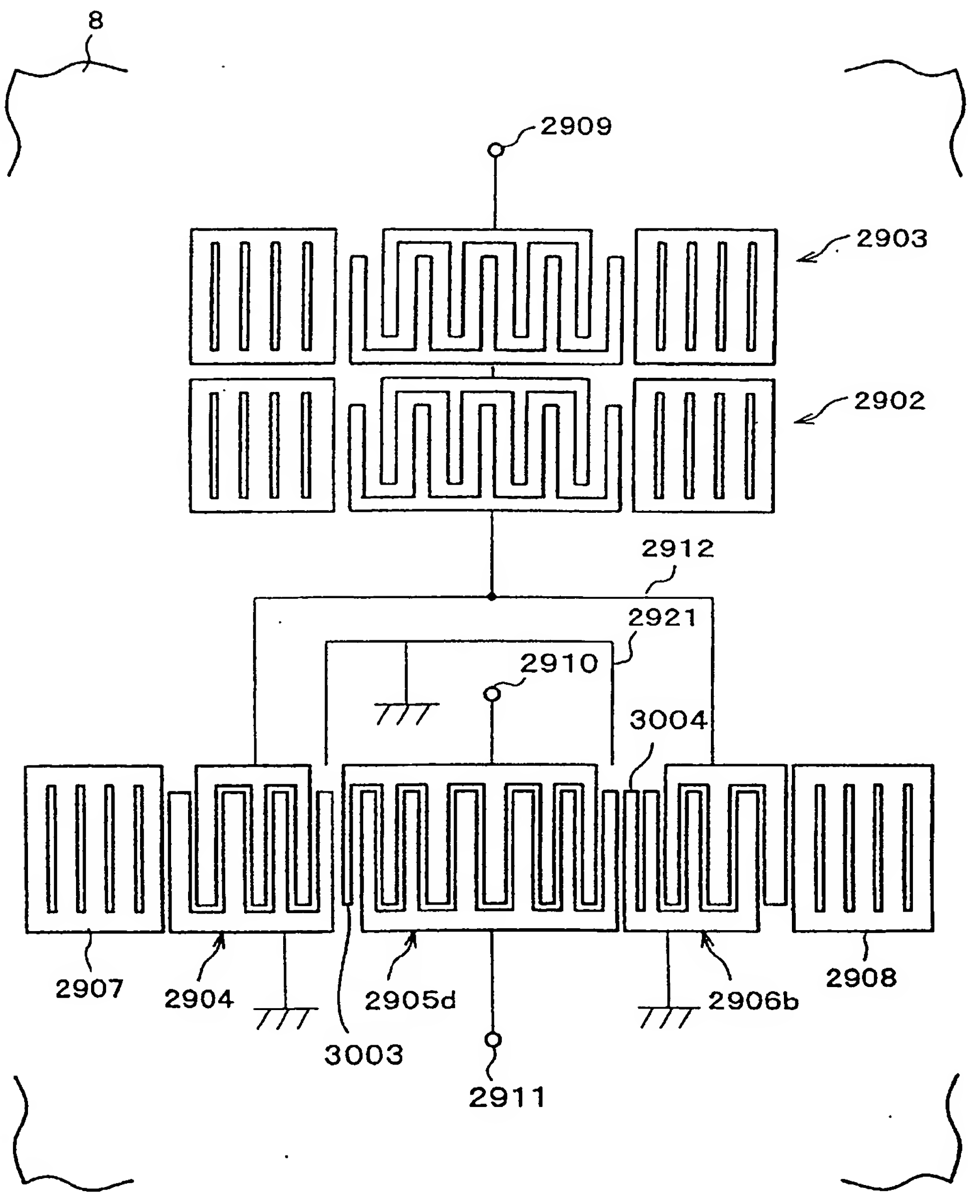

PASS BAND
EIGHTH EMBODIMENT
SECOND COMPARATIVE EXAMPLE
FREQUENCY (MHz)
PHASE BALANCE (deg.)
190
185
180
175
170
1920
1930
1940
1950
1960
1970
1980
1990
2000

FIG. 65


8
2909
2903
2902
2912
2921
2910
3004
2907
2904
2905d
2906b
2908
3003
2911

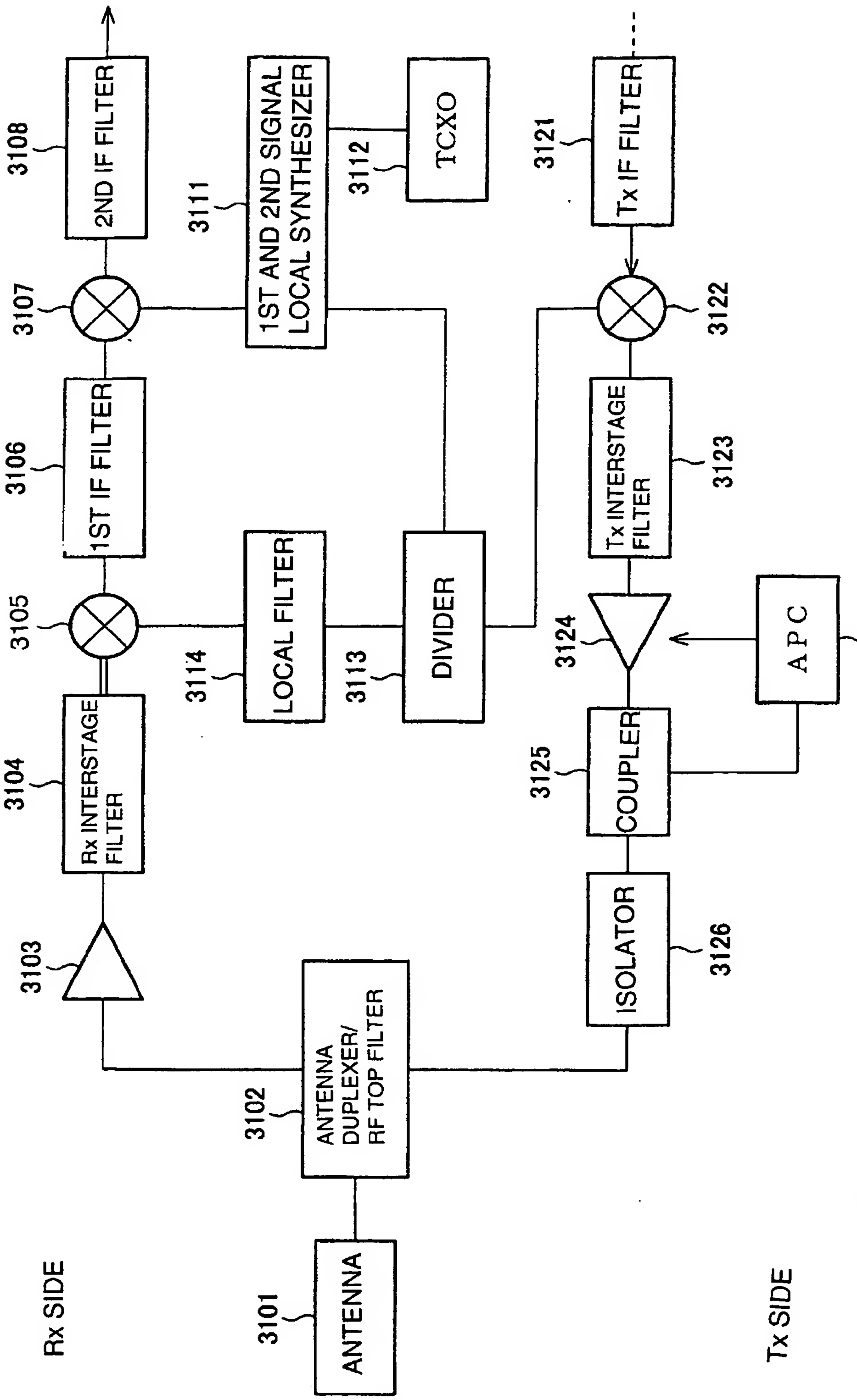

Rx SIDE
Tx SIDE
ANTENNA
3101
ANTENNA DUPLEXER/ RF TOP FILTER
3102
3103
Rx INTERSTAGE FILTER
3104
3105
1ST IF FILTER
3106
3107
2ND IF FILTER
3108
1ST AND 2ND SIGNAL LOCAL SYNTHESIZER
3111
TCXO
3112
DIVIDER
3113
LOCAL FILTER
3114
Tx IF FILTER
3121
3122
Tx INTERSTAGE FILTER
3123
3124
COUPLER
3125
ISOLATOR
3126
A P C
3127
3100

FIG. 66

FIG. 67

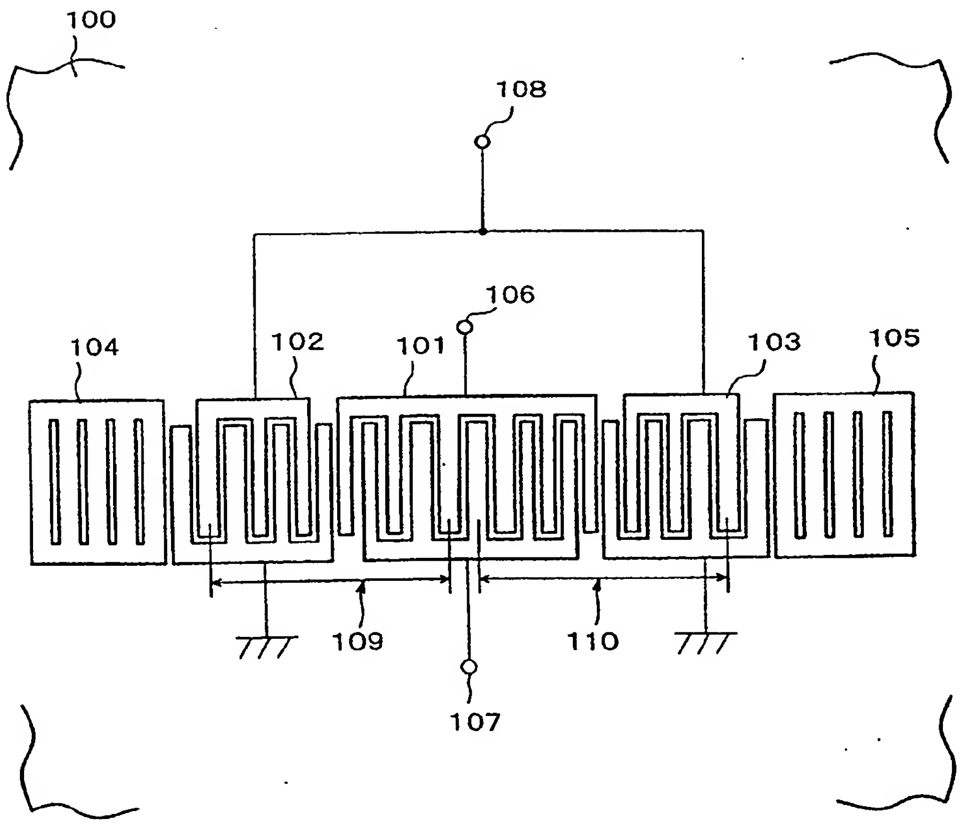


FIG. 68

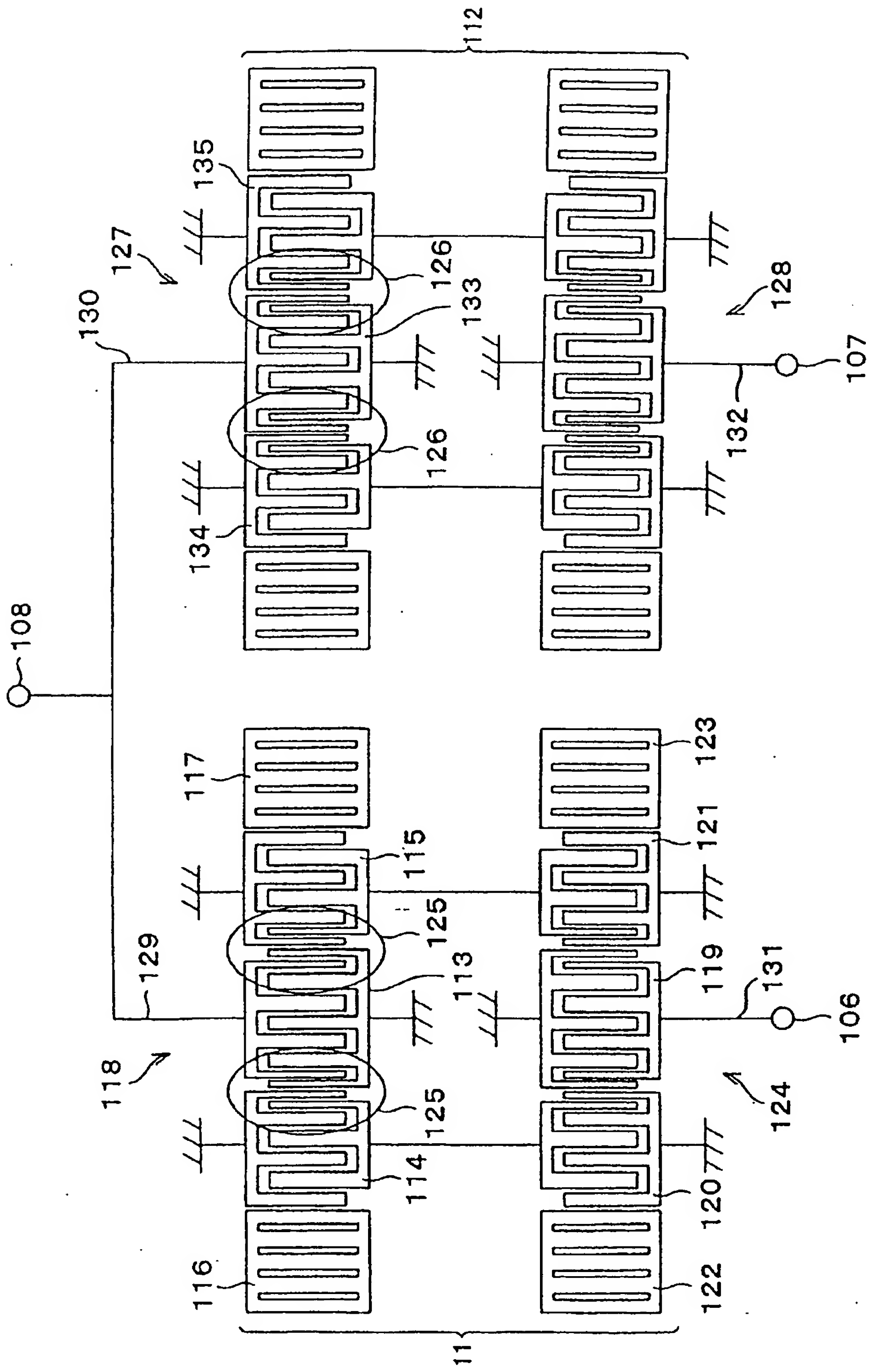
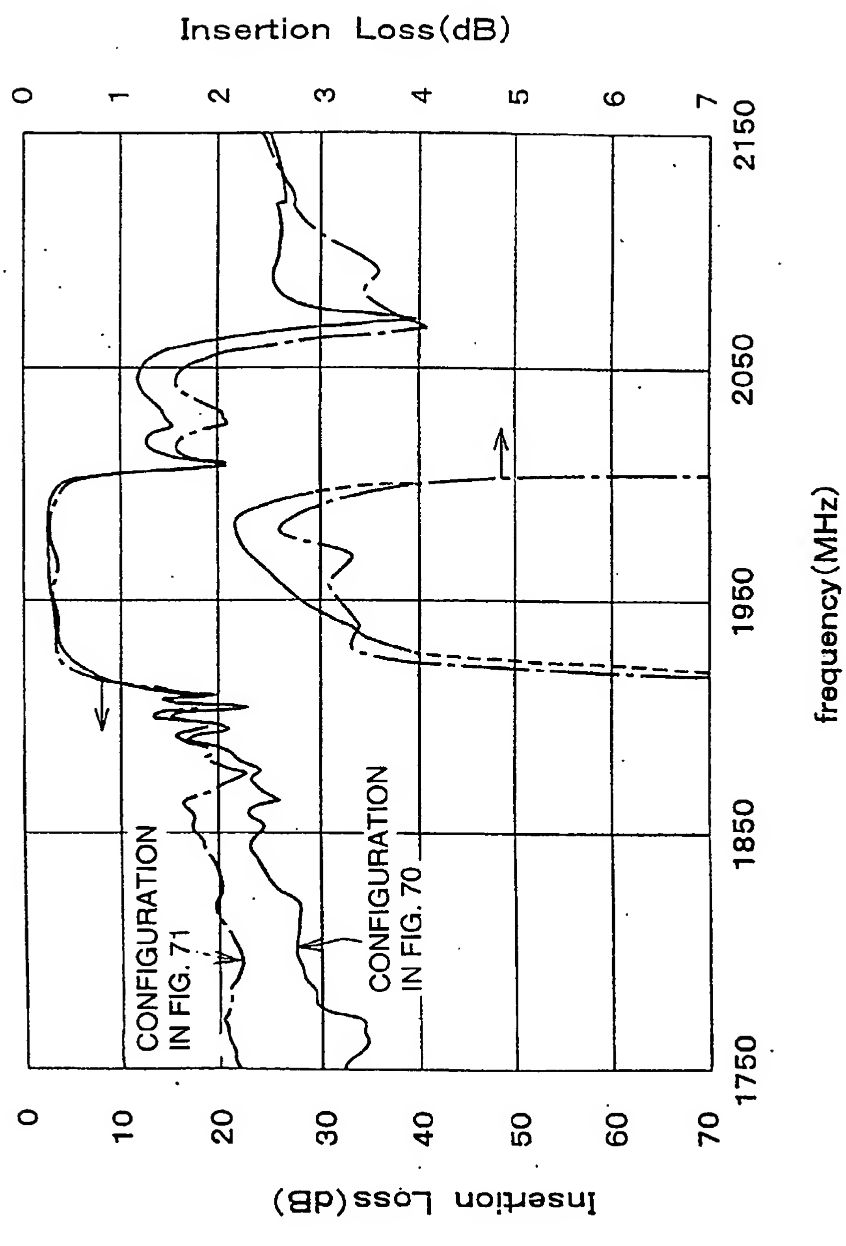

112
135
127
126
133
128
130
107
132
126
134
108
117
123
115
121
125
129
113
119
131
106
118
125
124
114
120
116
122
111

FIG. 69



Insertion Loss(dB)
0
1
2
3
4
5
6
7
Insertion Loss(dB)
0
10
20
30
40
50
60
70
1750
1850
1950
2050
2150
frequency(MHz)
CONFIGURATION IN FIG. 71
CONFIGURATION IN FIG. 70

FIG. 70

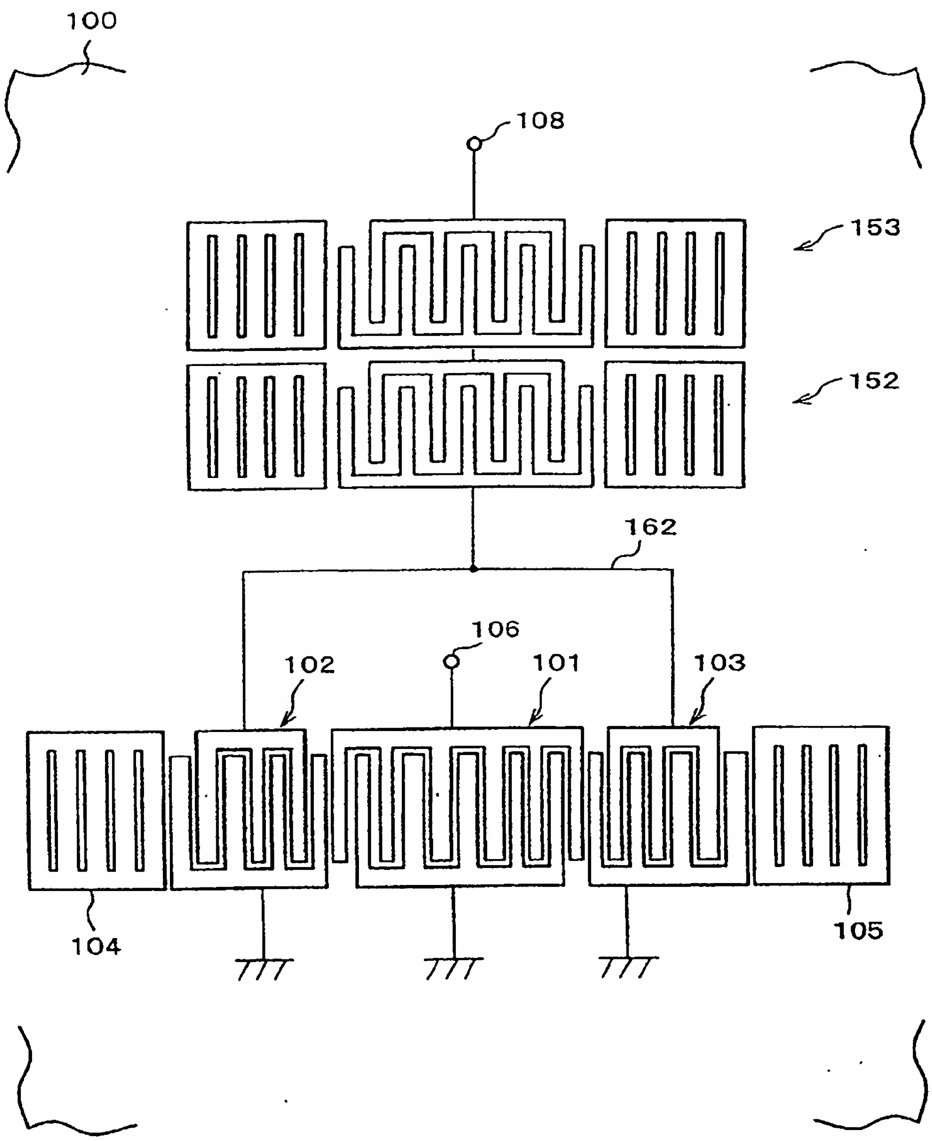


FIG. 71

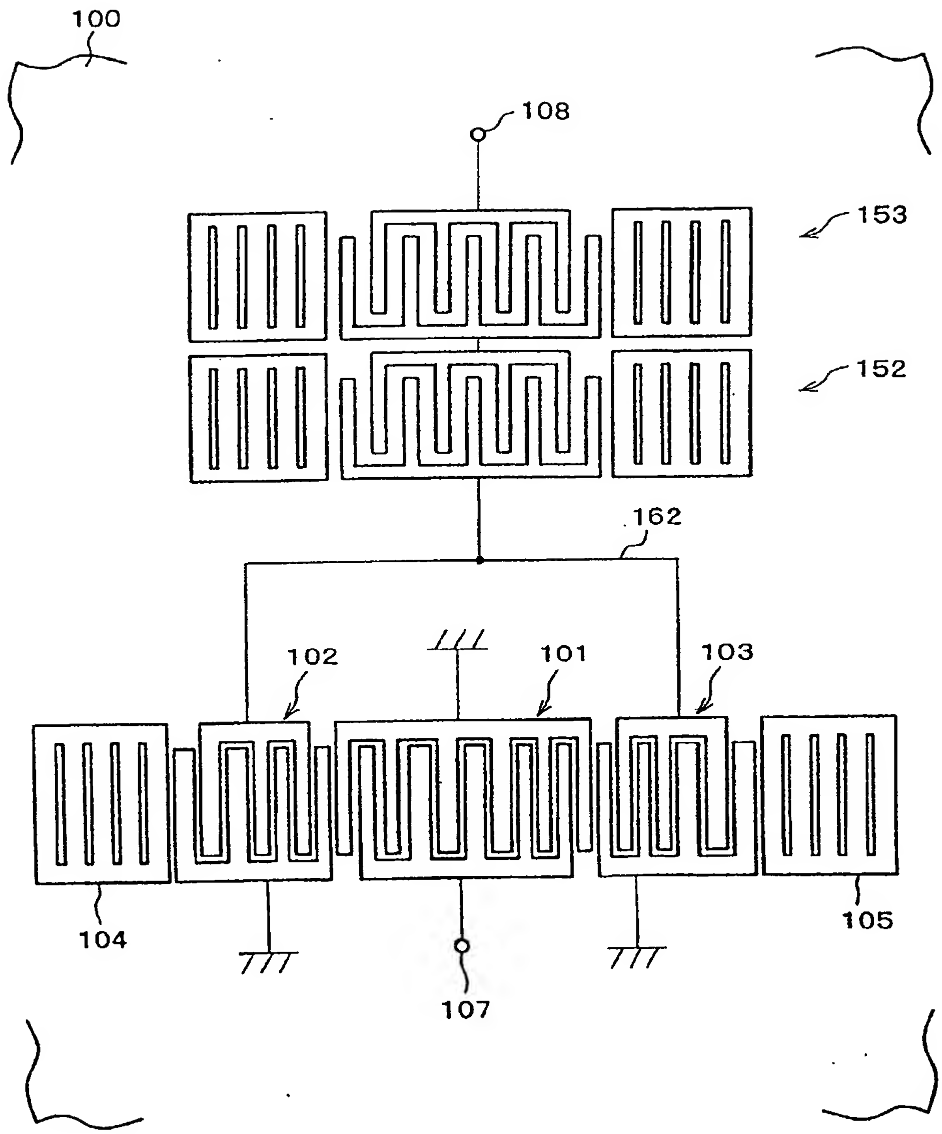


FIG. 72A

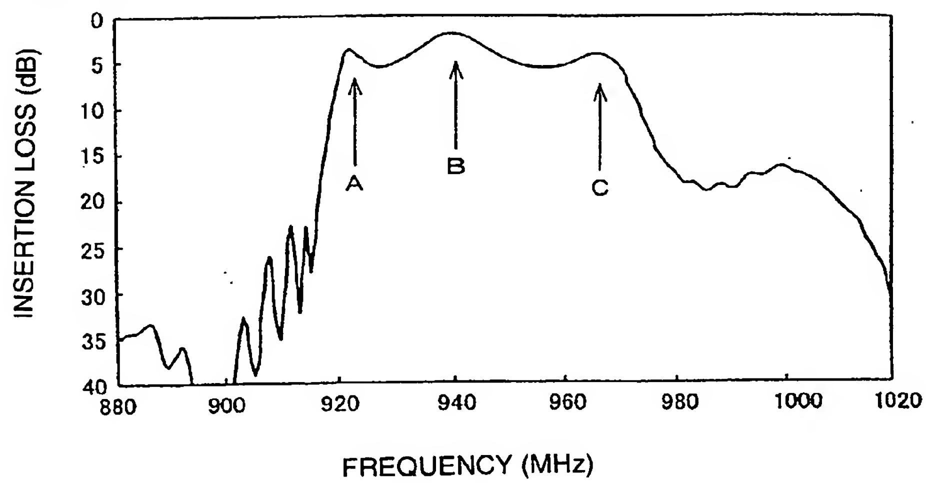


FIG. 72B

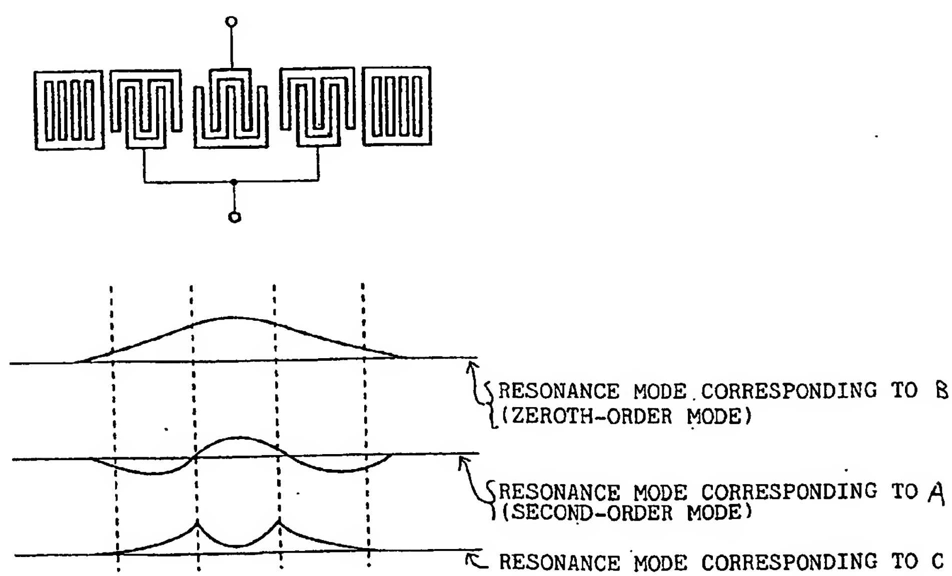


FIG. 73